# Study on the Reduction of Energy-Related Greenhouse Gas Emissions

Volume 1
Report & Appendix A

Ontario

Energy leadership

For economic strength

Ministry of Energy

Lyn McLeod
Minister

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Prepared by
The DPA Group Inc.

in association with
$CH_4$ International Ltd

RCG/Hagler, Bailly, Inc.
Steven G. Diener & Associates Ltd.

March, 1989

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VOLUME I

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## Disclaimer

This report has been reviewed by each of the contracting and funding agencies. The contents do not necessarily reflect the views and/or policies of any of those agencies. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

# EXECUTIVE SUMMARY

The Provincial, Territorial and Federal Energy Ministers formed a Task Force on Energy and the Environment in August 1988 to examine the options available for reducing carbon dioxide levels in Canada. This study was commissioned as a contribution to the work of the Task Force.

## Contributors to the Greenhouse Effect

The World Resources Institute estimates the man made contributions to the greenhouse effect to be as follows:[1]

| | |
|---|---|
| . carbon dioxide ($CO_2$) | 49% |
| . methane ($CH_4$) | 18% |
| . chlorofluorocarbons (CFCs) | 14% |
| . nitrous oxide ($N_2O$) | 6% |
| . other gases[2] | 13% |

This study examines ways to reduce emissions from the principal man made sources of carbon dioxide, chlorofluorocarbons and methane.

## Man Made Sources of Carbon Dioxide Emissions

The dominant man made source of carbon dioxide is the combustion of fossil fuels; coal, petroleum products and natural gas. This study focuses on ways to reduce carbon dioxide emissions from the principal fossil fuel uses in Canada. These uses include:

- space and water heating in the residential and commercial sectors;
- industrial use of oil, natural gas and coal for energy;
- transportation fuels; and
- generation of electricity from coal, oil and natural gas.

Feedstocks and other non-energy uses are not addressed.

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1 World Resources Institute as reported in The Economist, March 11, 1989, p87.

2 Ozone ($O_3$) in the troposphere contributes to the greenhouse effect. It is not emitted, but is synthesized in the troposphere through photochemical reactions involving nitrogen oxides ($NO_x$), water vapour and gaseous hydrocarbons.

Carbon monoxide (CO) and nitrogen oxides ($NO_x$) are not greenhouse gases, but they can significantly alter the chemistry of the atmosphere and so affect the concentrations of greenhouse gases.

Combustion of fossil fuels also causes emissions of methane and nitrogen oxides. The impact of measures to reduce carbon dioxide emissions on emissions of these gases is also addressed. The change in nitrogen oxides emissions is translated into a change in tropospheric ozone concentration.

The economic costs of carbon dioxide abatement measures and the regional impacts of these measures are discussed as well.

Man Made Sources of CFC and Methane Emissions

Chlorofluorocarbons are used in the manufacture, testing, maintenance and operation of a range of products. This study reviews the uses of CFCs, their possible substitutes and the status of national and international efforts to reduce CFC emissions.

Methane emissions are predominantly from natural sources. The largest man made sources are fugitive emissions from land fills, coal mines, the petroleum industry and similar sources. This study examines ways to reduce fugitive emissions from those sources.

Scope of the Study

Due to time limitations, this study was limited to a review and analysis of available information; no original research was undertaken.

The study is a technical analysis of potential measures to reduce energy related emissions of greenhouse gases. Policies to encourage implementation of any of the measures are beyond its scope. Analysis of the effects of reduced emissions on climate change also is outside the scope of the project.

The study takes a national perspective. Regional implications are discussed in broad terms. That discussion is not intended to be a substitute for detailed regional analyses.

The time frame for the analysis is the period to 2005. Implications for the period beyond 2005 are discussed briefly.

Reliability of the Results

An analysis of this type is inherently uncertain. It relies on forecasts of energy prices and demand, of technological developments, of the costs and performance of existing and new technologies, and a host of other factors subject to varying degrees of uncertainty. It also draws on numerous sources of varying accuracy.

The inherent uncertainty of the data means that caution should be exercised in interpreting the results relating to any specific measure or in attempting to apply the results to an individual province. However, the uncertainty relating to specific measures does not weaken the overall results.

This study provides the most detailed analysis of specific atmospheric greenhouse gas emission abatement measures of any study yet completed in Canada. In aggregate its findings are consistent with those of less detailed studies. This consistency with the findings of independent researchers provides a considerable level of confidence in the results.

Carbon Dioxide Emission Reduction Reference

A national objective for reduction of carbon dioxide emissions has not yet been established. But to study the options for reducing emissions, a target or point of reference is needed. The illustrative target used in this analysis is the one recommended by the June 1988 conference on "The Changing Atmosphere; Implications for Global Security"; specifically a 20 percent reduction from 1988 carbon dioxide emission levels by 2005.

Estimates of energy-related carbon dioxide emissions to the year 2005 are based on the national energy demand/supply forecast prepared by the Department of Energy, Mines and Resources. The forecast, prepared using the Inter-Fuel Substitution Demand (IFSD) model is based on the assumption that Texas crude oil prices rise from U.S. $15 per barrel in 1988 to U.S. $24 per barrel in 2005 (both in 1986 U.S. dollars).[3]

The energy-related carbon dioxide emissions estimated for 1988 are 419 million tonnes.[4] This means that the target for 2005, excluding emissions due to energy production, is annual carbon dioxide emissions of 336 million tonnes. The projected carbon dioxide emissions in 2005, based on the energy forecast, are 627 million tonnes.

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3 For a description of the forecast and the model see "Long-Term Energy Outlook 1987-2005", Energy Market Analysis Division, Energy, Mines and Resources Canada, June 1988.

4 Many publications dealing with carbon dioxide emissions express the emissions in terms of their carbon content. We will not follow that practice. The quantities reported in this study are carbon dioxide. To convert; 1 tonne of $CO_2$ contains 0.2725 tonnes of carbon, and emissions with a carbon content of 1 tonne are equal to 3.67 tonnes of carbon dioxide.

The energy demand forecast by the IFSD model for 2005 probably incorporates some improvement in energy efficiency in the interim. The extent of the energy efficiency gains is implicit in the model and can not be estimated easily. To adjust for these implicit energy efficiency improvements, the carbon dioxide emissions reduction target is expressed as a range.

Specifically, carbon dioxide abatement measures yielding a cumulative emissions reduction of 291 to 342 million tonnes per year must be implemented to meet the target.

Analysis of Potential $CO_2$ Emission Reductions

The analysis of the potential for reducing carbon dioxide emissions proceeds through three stages:

- direct reduction of carbon dioxide emissions through conservation, substitution and other measures that affect fossil fuel use in the residential, commercial, industrial and transportation sectors.

- indirect reduction of carbon dioxide through measures that affect the use of electricity in the residential, commercial, industrial and transportation sectors. Reduced demand for electricity lowers the use of fossil fuel used to generate electricity and so lowers carbon dioxide emissions.

- substitution of non-fossil generation for fossil fueled generation. This lowers carbon dioxide emissions by reducing the amount of fossil fuel used to generate electricity.

The carbon dioxide emission reductions that can be achieved by measures in each of these categories are discussed below.

Penetration of $CO_2$ Abatement Measures

Carbon dioxide emissions reductions are estimated for three levels of penetration of selected measures. Those levels of penetration are:

- technical potential;
- measures economically attractive to society (MEAS); and
- market penetration.

The technical potential is an estimate of the total number of installations that are technically possible in Canada by 2005.

Measures economically attractive to society are those that yield a net economic return to society.[5] Conservation measures are attractive if the value of the energy savings exceeds their cost. Fuel substitution and electricity generation measures are economically attractive if they are less costly than the best alternative. Although a measure may be economically attractive, the emission reductions are sometimes lower than the technical potential because the measure may not be attractive for all potential applications.

Estimated market penetration is the fraction of the technical potential likely to be achieved with no new policy measures to promote adoption.

Direct $CO_2$ Emission Reductions

Approximately 90 measures to reduce carbon dioxide emissions from the use of fossil fuels in the residential, multi-residential, commercial, industrial and transportation sectors were selected on the basis of their cost-effectiveness in lowering emissions.

In general, the measures that are most cost-effective in reducing carbon dioxide emissions are those that improve the efficiency of energy use. Measures that substitute other fuels for fossil fuels, alternative transportation fuels for example, are less cost-effective, at least to the year 2005.

The reduction in emissions that can be achieved by the selected measures that reduce carbon dioxide emissions directly is as follows:

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5 The net economic return is calculated as the net present value of the annual energy savings valued in terms of 1995 energy prices (expressed in 1988 dollars) less the initial cost of the measure. A real social discount rate of 7 percent is used to calculate the present value of the energy savings.

| | Market Penetration | Measures Economically Attractive to Society | Technical Potential | Technical Potential as a Share of 2005 $CO_2$ Emissions from the Sector |
|---|---|---|---|---|
| | (millions of tonnes annually by 2005) | | | |
| Residential | 3 | 10 | 20 | 45% |
| Multi-Residential | 2 | 4 | 6 | |
| Commercial | 4 | 12 | 25 | |
| Industrial | 4 | 9 | 40 | 24% |
| Transportation | 18 | 68 | 87 | 49% |
| TOTAL | 31 | 103 | 177 | 39% |

A recent American study estimated the technical potential for reduction of carbon dioxide emissions in the major end use sectors to be virtually identical to the above figures.[6]

Measures that Affect the Demand for Electricity

Over 50 measures selected affect the demand for electricity. The effects are felt in one of three ways:

- demand side management measures reduce the demand for electricity;
- electrotechnologies in the industrial sector substitute processes that use electricity for ones that use fossil fuel and so increase the demand for electricity; and
- cogeneration or by-product electricity increases the supply of electricity.

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6 The technical potential estimated for the combined residential and commercial sectors was 50%. The technical potential for the industrial sector was estimated at 25% and for the transportation sector was estimated at 50%.

The net impact of the measures that affect the supply of, or demand for, electricity is as follows:

| | Market Penetration | Economically Attractive to Society | Technical Potential | Technical Potential as % of Forecast 2005 Demand in the Sector |
|---|---|---|---|---|
| | (PJ Annually by 2005) | | | |
| Residential | 33 | 86 | 169 | 46% |
| Multi-Residential | 23 | 71 | 92 | |
| Commercial | 75 | 247 | 301 | |
| Industrial | 49 | 308 | 265 | 25% |
| Transport | - | -24 | -24 | |
| TOTAL | 180 | 688 | 803 | 35% |
| Reduction in $CO_2$ Emissions (millions of tonnes) | 20 | 76 | 88 | |

The industrial sector shows larger savings under MEAS than under technical potential. This is deceptive. The technical potential includes a number of electrotechnologies that increase the demand for electricity, but reduce the use of fossil fuels. This is reflected in a much larger direct reduction in carbon dioxide emissions in the industrial sector under technical potential.

The forecast growth in the secondary demand for electricity to 2005 is 794 PJ. The savings estimated to be possible under the technical potential are slightly larger than this growth in demand. The MEAS and market penetration scenarios both show growth in the demand for electricity and hence a requirements for new generation capacity.

The estimated potential for demand-side management measures is consistent with a recent New York study.[7]

The reduction in carbon dioxide emissions that can be achieved through more efficient use of electricity is estimated by assuming that the expansion of electrical generation capacity forecast by the IFSD model is cut back proportionately for each fuel type. The carbon dioxide emissions reduction is then estimated from the change in the generation capacity. The

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7 The study estimated the potential for conservation at approximately 34% of current demand in the residential sector, 50% in the commercial sector, 22% in the industrial sector and 38% overall.

reduction in emissions ranges from 20 to 88 million tonnes of carbon dioxide per year.

Substitution for Fossil Fueled Generation

The IFSD forecasts an expansion of non-fossil fueled -- hydroelectric and nuclear -- generation between 1988 and 2005. As a result of the lower demand for electricity achieved through the demand-side management measures much of that additional capacity is not needed. This non-fossil generation capacity could be built and substituted for new and existing fossil fueled generation. Other non-fossil generation technologies expected to be viable by 2005, such as photovoltaic, wind, tidal, geothermal and fuel cells, can be included in this process.

The non-fossil generation forecast by the IFSD model to be available by 2005 and no longer needed to meet the growth in demand for electricity is more than enough to completely displace all fossil fueled generation under both the MEAS and technical potential scenarios. The new generation technologies are not needed for this purpose.

The reductions in carbon dioxide emissions that can be achieved by substituting for fossil fueled generation are assumed to be nil under the market penetration scenario. Under the MEAS penetration scenario the carbon dioxide emission reductions are 42 million tonnes per year.

The technical potential scenario indicates potential carbon dioxide emissions reductions of 85 million tonnes per year. This last scenario requires replacement of all existing thermal generation capacity by 2005. That is estimated to have a net social cost of $15 billion although this would be partially offset by savings on measures to control emissions that contribute to acid rain.

Summary of Carbon Dioxide Reduction Potential

The estimates of carbon dioxide reduction potential can be summarized as follows:

| | Market Penetration | Measures Economically Attractive to Society | Technical Potential |
|---|---|---|---|
| | (millions of tonnes annually by 2005) | | |
| Savings due to energy efficiency measures | 31 | 103 | 177 |
| Savings due to electricity demand-side management measures | 20 | 76 | 88 |
| Savings due to replacement of existing and future fossil-fired electricity generation with non-fossil generation | NIL | 42 | 85 |
| Total Reduction | 51 | 221 | 350 |

The Toronto Climate Conference target requires a reduction of carbon dioxide emissions of 291 to 342 million tonnes per year. The technical potential exceeds that target regardless of the specific value chosen. The measures economically attractive to society achieve roughly 65 to 75 percent of the target. The market penetration achieves less than 15 percent of the target.

The finding that energy conservation measures offer the greatest potential for reduction of carbon dioxide emissions over the period to 2005 is consistent with U.S. findings.[8]

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8 J.A. Edmonds, W.B. Ashton, H.C. Cheng and M. Steinberg, "A Preliminary Analysis of U.S. $CO_2$ Emissions Reduction Potential from Energy Conservation and the Substitution of Natural Gas for Coal in the Period to 2010", U.S. Department of Energy, February 1989. The study concludes that larger contributions to $CO_2$ emissions reduction appear to be available through energy conservation than through substitution of natural gas for coal. Our results indicate that conservation measures (including conservation of electricity) accounts for roughly 75% of the total $CO_2$ emissions reduction. The relative magnitudes of the reductions due to conservation and substitution are consistent with the above study.

Interpretation of the Results

The results can be interpreted in two ways. Using technical potential as an example, energy efficiency measures covering fossil fuels and electricity generate about 75 percent of the total reduction in carbon dioxide emissions. The remaining 25 percent comes from fuel substitution in the electrical generation sector.

The second perspective is that of the electric utilities. They account for roughly half the total reduction in carbon dioxide emissions through promoting more efficient use of electricity and shifting to non-fossil generation. The emissions reductions in all other sectors combined equal those of the electric utilities.

The selected measures produce the greatest proportional reduction in emissions from electricity generation. The smallest proportional reduction occurs in the industrial sector. The pattern for the industrial sector is consistent with other studies which estimate relatively smaller potential for energy conservation and demand side management measures in that sector. It may also be partially due to the difficulties of obtaining a comprehensive picture of energy use in this very diverse sector.

These results reflect the selection of the most cost-effective abatement measures. Higher cost and/or less effective abatement measures are available and could be substituted for some of the measures selected. The higher cost/less effective measures may be preferred to the selected measures when all social objectives, rather than carbon dioxide abatement alone, and their economic impacts are considered.

Costs of Carbon Dioxide Emission Reductions

Most of the measures that reduce emissions of carbon dioxide also save energy. In many of these cases, the value of the energy saved over the life of the measure exceeds the initial investment required. As a result, the net cost of most of the measures is negative; that is they produce a net benefit. Most of the measures selected reduce carbon dioxide emissions, save energy and save money.

The total "cost" associated with the carbon dioxide emission reduction measures in each penetration scenario is as follows:

| Market Penetration | Measures Economically Attractive to Society | Technical Potential |
|---|---|---|
| | (billions of 1988 dollars) | |
| -$42 | -$150 | -$99 |

Implementing the measures economically attractive to society yields a net benefit of $150 billion dollars on the basis of energy savings alone. The technical potential scenario achieves larger carbon dioxide emissions reductions by including some measures that are not economically attractive to society. As a result the total net benefits, at $99 billion, are somewhat smaller than under MEAS. However, it is important to recognize that the technical potential scenario still yields a significant net benefit to society.

These economic benefits cannot be achieved without significant investment. The incremental capital investments required are estimated as follows:

| Market Penetration | Measures Economically Attractive to Society | Technical Potential |
|---|---|---|
| | (billions of 1988 dollars) | |
| $23 | $74 | $128 |

Impacts on Other Atmospheric Greenhouse Gases

Combustion of fossil fuel discharges small quantities of methane and nitrous oxide into the atmosphere. Emission factors are not available for nitrous oxide. The reductions in methane emissions achieved through implementation of the carbon dioxide abatement measures are estimated and expressed as carbon dioxide equivalent. The effect of the combustion-related methane emission reductions is equivalent to less than 0.10 percent of the carbon dioxide reductions.

Combustion of fossil fuels also releases nitrogen oxides ($NO_x$) into the atmosphere. There is a consensus that $NO_x$ plays a pivotal role in the formation of ozone in the troposphere. The carbon dioxide abatement measures reduce $NO_x$ emissions and so reduce ozone concentrations.

Assuming that the estimated changes in $NO_x$ emissions occur on a global basis, the tropospheric ozone concentrations will change from the current 20 to 100 ppbv as follows:

| | Market Penetration | Measures Economically Attractive to Society | Technical Potential |
|---|---|---|---|
| Reduction in 1988 concentration of tropospheric ozone (parts per billion/ volume) | 27-134 | 19-94 | 14-68 |

To express the change in tropospheric ozone concentration in terms of an equivalent reduction in carbon dioxide emissions requires complex climate modelling which is beyond the scope of this project.

Regional Impacts of $CO_2$ Reduction

Significant variations in the use of fossil fuels are found across Canada. These are due to weather conditions, availability of fuels, nature of the energy using equipment and other factors. These differences should be reflected in regional analyses, but detailed regional analyses were beyond the scope of this study.

Regional impacts are examined by assuming that each region is responsible for its share of the national emission reduction target based on its estimated 1988 carbon dioxide emissions. Other approches to apportioning the national carbon dioxide abatement target are possible. For example, apportioning the national target across sectors and then calculating the regional share of each sectoral target could produce significantly different regional targets.

Each region is assumed to achieve the national average reduction in direct emissions from each end-use sector. And the net electricity savings in each end-use sector are assumed to equal the national average. The regional impacts are then assessed terms of the consequences for electricity generation.

Electricity Generation Impacts by Region

Under the technical potential assumptions, the demand for electricity is lower in 2005 than in 1988 in all regions except Ontario.

Quebec is unable to achieve its carbon dioxide emissions reduction target in the manner outlined because it has very

little fossil fueled generation. Quebec would have to substitute non-fossil electricity for fossil fuels in the residential, commercial and industrial sectors to achieve its emissions reductions target.

Alberta and Saskatchewan are unable to meet their shares of the carbon dioxide emissions reduction in the manner outlined because they do not have enough non-fossil generation. Continued use of coal to generate the required electricity would exceed their emissions targets. However, conversion of existing generation capacity from conventional to combined cycle coal and/or natural gas would enable Alberta and Saskatchewan to meet their targets. There may also be opportunities to reduce carbon dioxide emissions in the production of fossil fuels or their use as feedstocks, which were beyond the scope of this study.

The Atlantic, Ontario, Manitoba and British Columbia regions should be able to achieve their carbon dioxide emission reduction targets in the manner outlined.

These impacts reflect regional implementation of the measures that are estimated to be the most cost-effective on a national basis. Regional carbon dioxide abatement targets can be established using different rules. And a region may choose to substitute less cost-effective abatement measures for selected measures after consideration of other social objectives. As a result regional carbon dioxide abatement strategies could be very different from a strategy based upon measures assessed on a national basis.

Beyond 2005

The most cost-effective strategy for the period to 2005 relies heavily on improved energy efficiency and substitution of non-fossil generation. The scope for continued improvements in energy efficiency will be smaller after 2005 because of the measures implemented in the interim.

After 2005 reductions in carbon dioxide emissions are likely to require greater reliance on displacement of fossil fuels in the end use sectors by non-fossil electricity. Research and development of non-fossil generation technologies is needed over the next 15 years to enhance the prospect of their becoming commercially available in the future.

Chlorofluorocarbons and Climate Warming

Chlorofluorocarbons (CFCs) contribute to climate warming in two ways:

- CFCs destroy stratospheric ozone which inhibits climate warming; and

. CFCs contribute directly to climate warming.

Molecule for molecule, the effect of CFCs on climate warming is about 10,000 times more powerful than that of carbon dioxide.

Uses and Properties of CFCs

CFCs are used as propellants in aerosols, in the manufacture of foams, refrigerants in air conditioners and refrigerators and as cleaning solvents. Halons, compounds related to CFCs, are used in fire extinguishes.

CFCs and halons are useful in these applications because they are versatile, non-toxic, non-flammable and have low thermal conductivity. They replaced more environmentally hazardous chemicals that were cancerous and/or flammable.

Data on the annual use of CFCs and halons are available. But emissions may not occur for many years after use, when the air conditioner, refrigerator, or fire extinguisher is taken out of service or the foam is crushed. CFCs and halons that have been used in such applications but not yet released to the atmosphere are said to be "banked".

Reduction of CFC Use

Efforts to control CFC emissions have been directed primarily at reducing the use, and ultimately emissions, of these compounds. A second area of interest is reducing the "bank" of halons and CFCs, although that often requires that a suitable substitute be found first.

Fortunately, substitutes or alternatives are available, or are expected to become available over the next 5 to 8 years, for most uses of CFCs and halons. Overall it is estimated that use of CFCs and halons can be reduced by 85 percent from current levels by 2000.

Measures to recover and destroy CFCs and halons that are now "banked" before they are released to the environment still need to be developed.

Plans to Reduce CFC Use

An international agreement, the Montreal Protocol, to limit emissions of CFCs and halons has been signed by 46 countries including Canada. It will reduce CFC consumption to 50 percent of 1986 levels by 1999.

Since the Montreal Protocol was drafted, scientific opinion has concluded that further reductions are needed. In recognition of this new consensus, Canada, Ontario and British Columbia have

announced their intention to reduce CFC use by 85 percent before 2000 and to eliminate all use as soon as safe substitutes are available.

Eventual elimination of these chemicals appears to be technically and economically achievable. Industry has indicated that it is prepared to cooperate in the achievement of that target. The main need is fair and reasonable regulation governing the reduced use of CFCs and halons.

Due to the uncertainty regarding the timing of CFC emissions and the very long life of CFCs in the atmosphere, it is not possible to establish an equivalence with carbon dioxide except through long term climate modelling.

Sources of Fugitive Methane Emissions

Fugitive methane emissions can be economically captured from:

- petroleum and natural gas production;
- coal mines;
- land fills;
- municipal wastewater treatment; and
- animal manures.

The estimated annual emissions of fugitive methane and the fraction of those emissions judged to be economically recoverable is as follows:

| Source | Estimated Annual Emissions of Methane (millions of $m^3$) | Fraction Estimated to be Economically Recoverable | Potential Reduction of Fugitive Emissions (1,000 tonnes) | Carbon Dioxide Equivalence (millions of tonnes) |
|---|---|---|---|---|
| coal mines | 500 | 0.5 | 180 | 10 |
| petroleum industry | 2,000 | 0.1 | 140 | 8 |
| land fills | 1,600 | 0.5 | 570 | 31 |

Capture of Fugitive Methane Emissions

Fugitive emissions in the petroleum industry are already carefully scrutinized. Due to the size of the industry, the emissions are still significant. But the potential for economic recovery is low.

Fugitive methane emissions can be recovered from underground coal mines. And it can be recovered from open pit coal mines before they are developed. A significant reduction in emissions could be achieved economically. Current efforts to reduce methane emissions from coal mines are negligible.

Land fills are the largest of the fugitive methane emission sources considered. Recovery and use can be economic for large land fills. Little recovery is currently practiced.

Anaerobic digestion of municipal wastewater and animal manures produces methane that can be economically recovered. Data on the potential for these applications are not available. Some western Canadian wastewater treatment plants capture methane and use it to generate electricity.

Conclusions

Chlorofluorocarbons. To date most efforts directed at reducing the greenhouse effect have focussed on CFCs. An international agreement, the Montreal Protocol, to reduce their use has been adopted by 46 countries.

Canada plans to exceed the provisions of the Protocol by reducing CFC use by 85 percent before 2000 and eliminating all use as soon as safe substitutes are available. This appears to be technically and economically achievable.

The main area yet to be addressed is the recovery and destruction of "banked" CFCs and halons before they are released to the environment.

Carbon Dioxide. Carbon dioxide is the largest single contributor to the greenhouse effect. Our analysis of the most cost-effective measures to reduce carbon dioxide emissions due to fossil fuel combustion, the principal man made source, indicates that:

- The Toronto Climate Conference target can be achieved, but only by doing virtually everything that is technically feasible to reduce carbon dioxide emissions.

- Implementing the measures needed to achieve the Toronto Climate Conference target also saves energy and yields economic benefits to society. Hence, neither excessive cost nor lack of proof that carbon dioxide contributes to climate warming is a valid excuse for inaction.

- Strong policy measures will be needed to achieve the Toronto Climate Conference target. Despite the fact that the measures are economically attractive to society, existing

policies (market penetration) yield only a small reduction in carbon dioxide emissions.

- Improved energy efficiency is generally the most cost-effective means of lowering carbon dioxide emissions. Such measures can achieve up to 75 percent of the target reduction by 2005.

- Substitution of non-fossil generation for fossil fueled generation of electricity accounts for the balance of the reduction in carbon dioxide emissions by 2005. To achieve the Toronto Climate Conference target almost all existing fossil fueled generation would need to be replaced.

The foregoing results are derived from selection of the carbon dioxide abatement measures that are most cost-efffective at the national level. Higher cost and/or less effective abatement measures are available and may be preferred when all social objectives are considered.

Application of the cost-effective national strategy on a regional basis indicates that Quebec, Saskatchewan and Alberta would experience the greatest difficulties meeting 20 per cent carbon dioxide reduction targets. Alternative procedures to apportion the national carbon dioxide abatement target and possible substitution of less cost-effective measures could give rise to different regional abatement strategies.

Fugitive Methane. Measures to capture and use fugitive methane are technically and economically feasible in many situations. The equivalent carbon dioxide abatement potential is approximately 10 to 15 percent of that of the carbon dioxide measures. The principal need is for regulations or incentives to encourage collection and use of the methane and to create markets for the gas and/or electricity produced.

the Toronto Climate Conference target almost all existing fossil fueled generation would need to be replaced.

- Significant regional differences are found in the ability to meet the Toronto Climate Conference target. It appears that Quebec, Saskatchewan and Alberta would experience the greatest difficulties meeting their carbon dioxide reduction targets. More detailed regional analyses are needed to confirm this finding.

Fugitive Methane. Measures to capture and use fugitive methane are technically and economically feasible in many situations. The equivalent carbon dioxide abatement potential is approximately 10 to 15 percent of that of the carbon dioxide measures. The principal need is for regulations or incentives to encourage collection and use of the methane and to create markets for the gas and/or electricity produced.

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# 1.0 INTRODUCTION

## 1.1 Background

An international conference on "The Changing Atmosphere: Implications for Global Security" held in Toronto in June 1988 focused attention on atmospheric risks associated with emissions from fossil fuel combustion. The Conference's final statement made specific recommendations for government action.

To address these issues, the Council of Provincial Energy Ministers (CPEM) agreed in August, 1988 to form a Task Force on Energy and the Environment. The Task Force was instructed to examine the options available to reduce carbon dioxide levels in Canada and the impacts of those options.

Specifically, the objectives of the Task Force are to:

1. Review the energy-related recommendations of the "Changing Atmosphere" conference, particularly the recommendation for a global reduction in carbon dioxide emissions of 20 percent of 1988 levels by the year 2005.

2. Assess the implications of these recommendations for Canada.

3. Evaluate the costs and benefits of options for responding to the recommendations.

4. Examine the consequences of these options for energy policy and planning.

5. Make recommendations for action by governments.

As a contribution to the work of the Task Force, a study on options for the reduction of energy-related atmospheric

greenhouse gas emissions in Canada was commissioned. This is the report on that study.

## 1.2 Study Objectives

The objectives of this study are to:

- determine the least-cost techniques for effecting a 20 percent reduction in carbon dioxide emissions in Canada by 2005;

- examine possible least-cost techniques for appropriate reductions in other greenhouse gases; and

- identify and discuss other cost-effective techniques which require an implementation timeframe beyond 2005.

## 1.3 Scope

This study provides a technical analysis of measures capable of reducing emissions of carbon dioxide and other greenhouse gases. It is the first step in the analysis of a large and complex topic. As such, it provides a quick overview of the subject, highlighting areas where further work is needed.

The study is national in scope. Regional impacts and benefits are noted, and discussed where appropriate, but they are not the primary focus of the analysis.

The timeframe for the analysis is the period to 2005. Cost-effective techniques to reduce emissions of carbon dioxide and other atmospheric greenhouse gases that involve implementation after 2005 are discussed, but are not central to the analysis.

The greenhouse gases covered by the study are carbon dioxide, carbon monoxide, nitrous oxide, chlorofluorocarbons (CFCs), methane and tropospheric ozone.[1] To analyse the effects of proposed abatement techniques on tropospheric ozone, it is necessary to consider as well nitrogen oxides ($NO_x$) and non methane volatile organic compounds (VOCs).

The study is a technical analysis of potential measures to reduce greenhouse gas emissions. Policies to encourage implementation of any of the measures are beyond its scope. Analysis of the effects of reduced emissions on climate change also is outside the scope of the project.

Due to time limitations the analysis was limited to a review and analysis of available information. No original research was undertaken.

### 1.4 Reliability of the Results

An analysis of this type is inherently uncertain. It relies on forecasts of energy prices and demand, of technological development, of the costs and performance of existing and new technologies, and a host of other factors subject to varying degrees of uncertainty. It also draws on numerous data sources of varying accuracy.

The inherent uncertainty of the data means that caution should be exercised in interpreting the results relating to any specific measure or in attempting to apply the results to an individual province. However, the uncertainty relating to specific measures does <u>not</u> weaken the overall results.

---

1 Carbon monoxide (CO) and nitrogen oxides ($NO_x$) are not themselves greenhouse gases, but they can significantly alter the chemistry of the atmosphere and so affect the concentrations of greenhouse gases.

This study provides the most detailed analysis of specific atmospheric greenhouse gas emission abatement measures of any study yet completed in Canada. In aggregate its findings are consistent with those of less detailed studies. This consistency with the findings of independent researchers provides a considerable level of confidence in the results.

## 1.5 Background

### 1.5.1 Estimated Contributions to the Greenhouse Effect

The World Resources Institute estimates the man made contributions to the greenhouse effect to be as follows:[2]

| | |
|---|---|
| . carbon dioxide | 49% |
| . methane | 18% |
| . chlorofluorocarbons | 14% |
| . nitrous oxide | 6% |
| . other gases | 13% |

The contribution of a particular gas to the greenhouse effect reflects its potency in reradiating infrared heat and the amount of the gas in the atmosphere. Current emissions have only a small impact on the amount of a gas in the atmosphere because the gases have radiatively active lives ranging from decades to centuries.

---

2 World Resources Institute as reported in The Economist, March 11, 1989, page 87.

### 1.5.2 Sources of Atmospheric Greenhouse Gas Emissions Analysed

This study examines ways to reduce emissions from the principal man made sources of carbon dioxide, chlorofluorocarbons and methane.

The dominant man made source of carbon dioxide is the combustion of fossil fuels; coal, petroleum products and natural gas. This study focuses on ways to reduce carbon dioxide emissions from the principal fossil fuel uses in Canada. These uses include:

- space and water heating in the residential and commercial sectors;
- industrial use of oil, natural gas and coal for energy;
- transportation fuels; and
- generation of electricity from coal, oil and natural gas.

Feedstocks and other non-energy uses are not addressed.

Combustion of fossil fuels also causes emissions of methane and nitrogen oxides. The impact of measures to reduce carbon dioxide emissions on emissions of these gases is also addressed. The change in nitrogen oxides emissions is translated into a change in tropospheric ozone concentration.

Chlorofluorocarbons are used in the manufacture, testing, maintenance and operation of a range of products. This study reviews the uses of CFCs, their possible substitutes, and the status of national and international efforts to reduce CFC emissions.

Methane emissions are predominantly from natural sources. The largest man made sources are fugitive emissions from land fills, coal mines, the petroleum industry and similar sources. This study examines ways to reduce fugitive emissions from those sources.

### 1.5.3 Sources of Carbon Dioxide Emissions due to Energy Combustion

Carbon dioxide emissions from energy combustion in Canada, the largest source of man made emissions, amounted to almost 400 million tonnes in 1987.[3] Carbon dioxide dominates the energy combustion related emissions, as shown in Exhibit 1.1, accounting for over 98 percent of total emissions by weight.

Coal, natural gas and petroleum products are all major sources of carbon dioxide emissions.[4] Comparing the energy use and carbon dioxide emissions by fuel type indicates that coal is the most carbonaceous, followed by petroleum products and natural gas.

On a sectoral basis, transportation and industry are the dominant sources of carbon dioxide emissions, each accounting about 30 per cent of the total. Electricity generation accounts for just over

---

3 Many publications dealing with carbon dioxide emissions express the emissions in terms of their carbon content. We will not follow that practice. The quantities reported in this study are carbon dioxide. To convert; 1 tonne of $CO_2$ contains 0.2725 tonnes of carbon, and emissions with a carbon content of 1 tonne are equal to 3.67 tonnes of carbon dioxide.

4 Wood and other biomass energy sources are usually excluded from analyses of carbon dioxide emissions in developed countries. They account for only a small fraction of total energy use and the data are often less reliable than those for other energy sources. But the more fundamental reason for excluding them is the difficulty of determining the net contribution to carbon dioxide emissions. Trees absorb carbon dioxide from the atmosphere while growing. An equal amount of carbon dioxide is released to the atmosphere when the wood decays or is burned. Hence, burning wood has no net effect on total emissions, but it does affect the timing of the emissions. If trees harvested for fuel are replaced more quickly than trees that decay naturally, the effects on the timing of emissions may also be offset.

**EXHIBIT 1.1: ESTIMATED ENERGY COMBUSTION RELATED EMISSIONS OF ATMOSPHERIC GREENHOUSE GASES, CANADA, 1987 (TONNES)**

| | TONNES | | | | | PERCENT | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | NOx | Other VOC s | CO | CH4 | CO2 | NOx | Other VOC s | CO | CH4 | CO2 | ENERGY |
| FUEL | | | | | | | | | | | |
| Coal | 458,224 | 2,463 | 19,542 | 1,227 | 97,207,363 | 42.1% | 2.6% | 5.0% | 27.2% | 24.6% | 18.4% |
| Natural Gas | 207,584 | 3,263 | 28,232 | 2,100 | 111,815,820 | 19.1% | 3.4% | 7.3% | 46.5% | 28.3% | 27.8% |
| Oil | 422,632 | 90,823 | 340,986 | 1,186 | 186,338,877 | 38.8% | 94.1% | 87.7% | 26.3% | 47.1% | 39.4% |
| TOTAL | 1,088,440 | 96,549 | 388,760 | 4,513 | 395,362,061 | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| SECTOR | | | | | | | | | | | |
| Electricity & Steam | 397,054 | 2,803 | 15,296 | 765 | 86,393,965 | 36.5% | 2.9% | 3.9% | 17.0% | 21.8% | 31.2% |
| Energy Producers (a) | 128,219 | 572 | 11,301 | 256 | 38,716,973 | 11.8% | 0.6% | 2.9% | 5.7% | 9.8% | |
| Coke | 75,366 | 287 | 2,153 | 108 | 15,940,645 | 6.9% | 0.3% | 0.6% | 2.4% | 4.0% | |
| Mining | 29,049 | 4,381 | 9,183 | 178 | 8,277,663 | 2.7% | 4.5% | 2.4% | 3.9% | 2.1% | |
| Pulp & Paper | 25,985 | 2,167 | 5,477 | 301 | 10,346,405 | 2.4% | 2.2% | 1.4% | 6.7% | 2.6% | |
| Iron & Steel | 6,626 | 205 | 1,351 | 120 | 4,306,198 | 0.6% | 0.2% | 0.3% | 2.7% | 1.1% | |
| Smelting | 7,720 | 125 | 764 | 61 | 2,936,055 | 0.7% | 0.1% | 0.2% | 1.4% | 0.7% | |
| Cement | 14,638 | 425 | 1,255 | 61 | 3,917,798 | 1.3% | 0.4% | 0.3% | 1.4% | 1.0% | 23.4% |
| Petroleum Refining | 4,407 | 87 | 1,102 | 94 | 3,741,462 | 0.4% | 0.1% | 0.3% | 2.1% | 0.9% | |
| Chemicals | 11,134 | 253 | 2,453 | 224 | 8,276,756 | 1.0% | 0.3% | 0.6% | 5.0% | 2.1% | |
| Other Manufacturing | 36,135 | 3,156 | 10,723 | 442 | 19,267,485 | 3.3% | 3.3% | 2.8% | 9.8% | 4.9% | |
| Forestry | 7,721 | 1,596 | 2,642 | 7 | 1,064,359 | 0.7% | 1.7% | 0.7% | 0.2% | 0.3% | |
| Construction | 16,153 | 3,460 | 5,942 | 3 | 2,142,245 | 1.5% | 3.6% | 1.5% | 0.1% | 0.5% | |
| Pipelines | 4,157 | 248 | 858 | 107 | 4,748,393 | 0.4% | 0.3% | 0.2% | 2.4% | 1.2% | |
| Road | 153,595 | 45,861 | 195,376 | 3 | 89,952,918 | 14.1% | 47.5% | 50.3% | 0.1% | 22.7% | 19.9% |
| Other Transportation | 30,008 | 6,954 | 27,553 | 112 | 15,329,161 | 2.8% | 7.2% | 7.1% | 2.5% | 3.9% | |
| Commercial | 73,536 | 13,599 | 41,791 | 465 | 35,080,047 | 6.8% | 14.1% | 10.7% | 10.3% | 8.9% | 11.1% |
| Residential | 66,937 | 10,371 | 53,539 | 1,205 | 45,171,641 | 6.1% | 10.7% | 13.8% | 26.7% | 11.4% | 14.4% |
| TOTAL | 1,088,440 | 96,550 | 388,759 | 4,512 | 395,610,171 | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |

Notes: a) Emissions by coal and natural gas produces and petroleum refineries.

Sources: Estimated by the The DPA Group from Statistics Canada, Quarterly Report on Energy Supply-Demand in Canada, 1987-iv, July, 1988; Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources and Volume 2: Mobile Source, AP-42, Fourth Edition, September 1985, U.S. Environmental Protection Agency; and $CO_2$ emissions factors supplied by Dr. Jay Edmonds, Battelle Pacific Northwest Laboratories.

20 per cent of carbon dioxide emissions while the residential and commercial sectors combined account for roughly 20 per cent of the total.

### 1.5.4 Trends in Carbon Dioxide Emissions

The pattern of carbon dioxide emissions due to energy combustion in Canada since 1950 is shown in Exhibit 1.2. While the data in the exhibit do not correspond exactly with those in Exhibit 1.1, it is the pattern that is of interest. Carbon dioxide emissions rose from 345 million tonnes in 1975 to about 380 million tonnes in 1979 before falling back to 350 million tonnes in 1983. Between 1983 and 1986 carbon dioxide emissions ranged between 345 and 360 million tonnes per year.

The recent trend in carbon dioxide emissions might suggest that the problem is under control and no further action is needed. But the recent pattern reflects the oil price shocks of 1973-74 and 1979-80, the severe recession of 1982 as well as improvements in energy efficiency and increased use of alternative energy sources. All of these developments reduced the use of energy and consequently lowered carbon dioxide emissions.

The recent decline in carbon dioxide emissions is not forecast to continue. The most recent national energy supply/demand forecast prepared by the Department of Energy, Mines and Resources implies a sharp increase in carbon dioxide emissions as shown below.[5]

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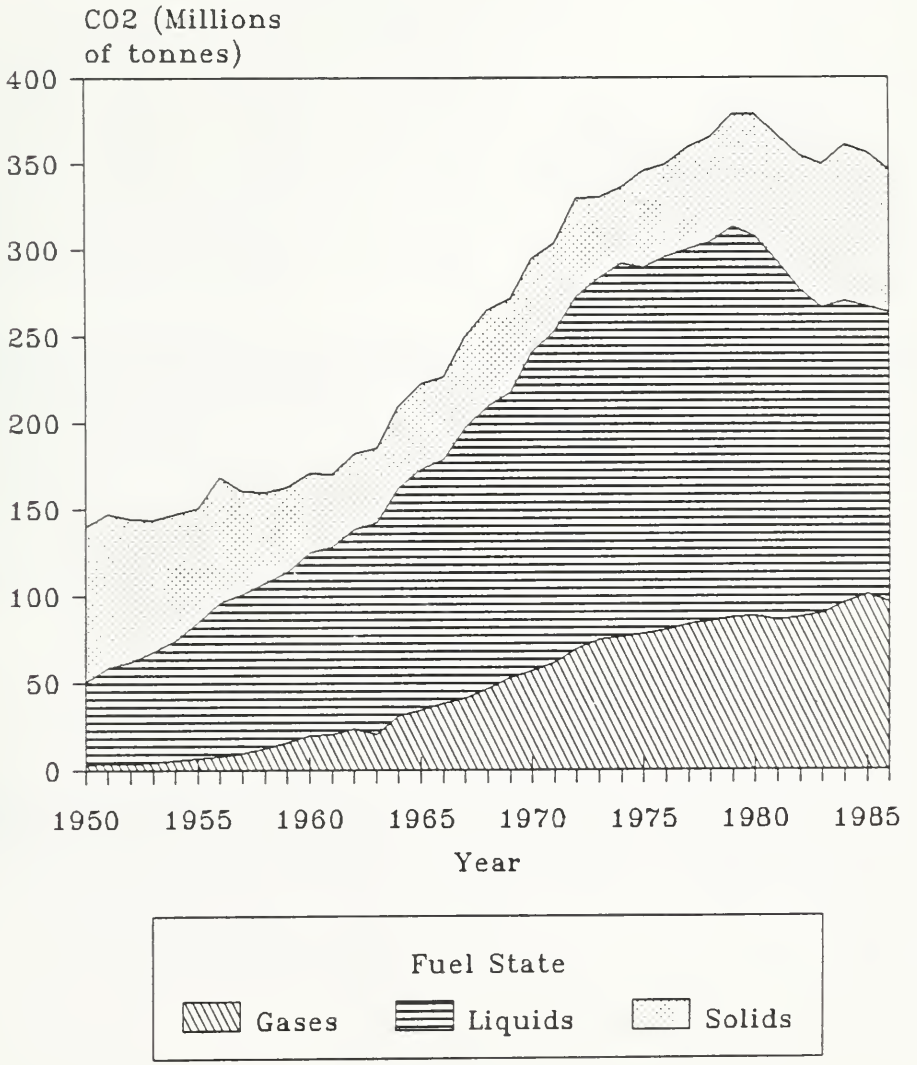
[5] For a description of the forecast see "Long-Term Energy Outlook 1987-2005", Energy Market Analysis Division, Energy, Mines and Resources Canada, June 1988. The forecast used in this study is based on the assumption that Texas crude oil prices rise from U.S. $15 per barrel in 1988 to U.S.$24 per barrel in 2005 (both in 1986 U.S. dollars).

**EXHIBIT 1.2: PRODUCTION OF CARBON DIOXIDE IN CANADA**



PROJECTED CARBON DIOXIDE EMISSIONS
(Millions of Tonnes of $CO_2$ Annually)

| | 1988 | 2005 | 1988-2005 Growth |
|---|---|---|---|
| Residential Sector | 53 | 61 | 15% |
| Commercial Sector | 32 | 49 | 53% |
| Industrial Sector | 121 | 163 | 35% |
| Transportation Sector | 128 | 180 | 40% |
| Electricity Generation | 85 | 174 | 104% |
| TOTAL | 419 | 627 | 50% |

The energy forecast implies that carbon dioxide emissions could increase by 50 percent by 2005. This reflects projected growth of the economy and a corresponding increase in the demand for energy of all types.

## 1.6 Approach

The study is divided into three separate analyses:

- a review of the prospects for reduced use of chlorofluorocarbons (CFCs);
- a review of methods to capture fugitive methane emissions from selected sources; and
- analysis of measures to reduce emissions of carbon dioxide and other atmospheric greenhouse gases due to combustion of fossil fuels.

These three aspects of the study are described briefly below.

### 1.6.1 Review of the Prospects for Reduced use of Chlorofluorocarbons and Halons

Chlorofluorocarbons and halons are used in refrigerators and air conditioners, the manufacture of insulating and other foams, aerosol propellants, cleaning fluids and fire extinguishers. Reduced use, and ultimately lower emissions, of CFCs and halons is most likely to be achieved through the use of substitutes. The availability of substitutes in each application is reviewed. This is translated into an estimate of the potential for reduced use of CFCs and halons in Canada by 2005. This topic is addressed in Appendix B and covered in summary form in Chapter 4.

### 1.6.2 Review of Fugitive Methane Emissions from Selected Sources

The sources of fugitive emissions reviewed are coal mines, the petroleum industry, land fills and biogas sources. The techniques of methane recovery and use from each source are reviewed. Estimates of the emissions that are economically recoverable are then developed. This topic is covered in Appendix C and presented in summary form in Chapter 4.

### 1.6.3 Measures to Reduce Emissions of Greenhouse Gases due to Combustion of Fossil Fuels

The main focus of the study is measures to reduce emissions of atmospheric greenhouse gas emissions due to the combustion of fossil fuels. The analysis does not cover non-energy uses of fossil fuels, such as feedstocks, nor own use of energy by energy producers and transporters.

Process-related emissions of the greenhouse gases are not included in the calculations. For example, carbon dioxide emissions from the fuel used to manufacture cement are part of the study, but the carbon dioxide emitted by the chemical

reactions involved in the manufacture of cement are not part of the analysis.

Possible measures to reduce atmospheric greenhouse gas emissions due to energy combustion are grouped into the following categories:

- conservation to reduce fossil fuel use;
- substitution of less carbonaceous fuels;
- substitution of non-carbon energy sources;
- removal of greenhouse gases from combustion emissions; and
- recycling of greenhouse gases.

The study focuses on measures that can have an appreciable effect on atmospheric greenhouse gas emissions by 2005. Cost-effectiveness in terms of reducing carbon dioxide emissions is the principal criterion for evaluating the potential abatement measures.

The methodology used for this analysis is described in Appendix A. Detailed data on the carbon dioxide abatement measures considered and the potential reductions of greenhouse gas emissions are presented in Appendix E. The procedure used to estimated the impact of lower nitrogen oxides emissions on tropospheric ozone concentrations is presented in Appendix D.

## 1.7 Structure of the Report

The core of the study is a technical analysis of measures to reduce emissions of greenhouse gases due to combustion of fossil fuels. Chapter 2 describes the approach used for that analysis. The results are presented in Chapter 3. The potential reduction of CFCs and methods to reduce fugitive methane emissions are summarized in Chapter 4. Our conclusions are found in Chapter 5.

# 2.0 APPROACH: REDUCTION OF COMBUSTION-RELATED EMISSIONS

## 2.1 Introduction

This chapter provides an overview of the methodology used to analyse measures with the potential to reduce emissions of carbon dioxide from fossil fuel combustion. More extensive description of the methodology is provided in Appendix A. Detailed data on the individual measures are presented in Appendix E.

## 2.2 Identification of Carbon Dioxide Abatement Measures

Measures with the potential to reduce emissions of greenhouse gases due to combustion of fossil fuels were identified from the available literature. Potential measures were classified into the following categories; measures that:

- conserve energy and so reduce fossil fuel use;
- substitute a less carbonaceous fuel for a more carbonaceous fuel;
- substitute a non-carbon energy source for a carbonaceous fuel;
- remove greenhouse gases from combustion emissions; and
- recycle greenhouse gases.

## 2.3 How are Carbon Dioxide Abatement Measures Defined?

Each measure is defined in terms of a "typical" installation, such as a house, an automobile, a square metre of commercial floor space, or an industry sector, for which energy performance and financial data are available.

A measure typically involves a specific end use or application and fuel; for example, a building envelope retrofit for homes heated with natural gas. As the example indicates a certain

amount of aggregation is needed. A building envelope retrofit may include a variety of specific measures such as ceiling, wall and basement insulation, caulking and weather tightening, storm windows, etc. The "building envelope retrofit" measure used in the analysis reflects a typical mix of these specific measures.

The change in emissions due to a building envelope retrofit depends upon the fuel used for space heating. Thus, it is necessary to define three "building envelope retrofit" measures; one each for natural gas, light fuel oil and electricity. The need to define measures in terms of the existing fuel increases the number of measures that must be included in the analysis.

## 2.4 Data Relating to Carbon Dioxide Abatement Measures

Each measure is documented in terms of its:

- energy performance;
- cost characteristics;
- potential number of installations;
- reduction of greenhouse gas emissions;
- cost-effectiveness in terms of emission reductions; and
- potential for emissions abatement.

Data on each measure are presented in Appendix E.

The number of measures identified is so numerous that they are organized into six sectors, as follows:

- residential;
- multi-residential;
- commercial and institutional;
- industrial (general and specific industries);
- transportation; and
- electricity generation.

## 2.5 Analysis of Potential Carbon Dioxide Emission Reductions

The analysis of the potential for reducing carbon dioxide emissions proceeds through three stages:

- direct reduction of carbon dioxide emissions through conservation, substitution and other measures that affect fossil fuel use in the residential, commercial, industrial and transportation sectors.

- indirect reduction of carbon dioxide through measures that affect the use of electricity in the residential, commercial, industrial and transportation sectors. Reduced demand for electricity lowers the use of fossil fuel used to generate electricity and so lowers carbon dioxide emissions.[6]

- substitution of non-fossil generation for fossil fueled generation. This lowers carbon dioxide emissions by reducing the amount of fossil fuel used to generate electricity.

In some instances more than one abatement option is available; various alternative transportation fuels for example. The most cost-effective measure is selected for each situation.

---

[6] Measures that increase the use of electricity, such as electrotechnologies in the industrial sector, and increase the supply of electricity, such as co-generation, are also covered in the analysis. The net effect, however, is a reduction in the demand for electricity from what it is forecast to be.

## 2.6 Penetration of Carbon Dioxide Abatement Measures

Carbon dioxide emissions reductions are estimated for three levels of penetration of selected measures. Those levels of penetration are:

- technical potential;
- measures economically attractive to society (MEAS); and
- market penetration.

The technical potential is an estimate of the total number of installations that are technically possible in Canada by 2005.

Measures economically attractive to society are those that yield a net economic return to society.[7] Conservation measures selected yield energy savings that exceed the cost of the measure. Substitution and electrical generation measures are less costly than the best alternative. Although a measure may be economically attractive, the emission reductions are sometimes lower than the technical potential because the measure may not be attractive for all potential applications.

Estimated market penetration is the fraction of the technical potential likely to be achieved with no new policy measures to promote adoption.

## 2.7 Impact on Tropospheric Ozone

Measures that reduce carbon dioxide emissions also reduce emissions of other gases. Reductions in combustion related

---

7 The economic attractiveness is evaluated in terms of the net measure cost. The net measure cost is calculated using 1995 energy prices (expressed in 1988 dollars) and a real social discount rate of 7 percent.

emissions of methane are expressed in terms of their carbon dioxide equivalence.

Reduced emissions of nitrogen oxides ($NO_x$) will lower the concentration of ozone in the troposphere. The relationship between $NO_x$ emissions and ozone concentration is reviewed in Appendix D. That relationship is used to estimate the effect of selected carbon dioxide abatement measures on tropospheric ozone concentration.

# 3.0 REDUCTION OF COMBUSTION-RELATED EMISSIONS OF CARBON DIOXIDE

## 3.1 Carbon Dioxide Emissions Reduction Reference

### 3.1.1 Specification of a Target

A national objective for reduction of carbon dioxide emissions has not yet been established. To study the feasibility of achieving a significant reduction in emissions of carbon dioxide and other greenhouse gases due to fossil fuel combustion a specific target or point of reference is needed. The illustrative target used in this analysis is the one recommended by the Toronto Climate Conference. That target is a 20 percent reduction from 1988 carbon dioxide emission levels by 2005.

The role of the target reduction is simply to specify the spectrum of carbon dioxide emission abatement measures needed; in other words what measures are needed to reduce carbon dioxide emissions by "X" million tonnes annually. The Toronto Climate Conference target is one way of defining this amount. It is used here because of the public awareness of this target and because it is an ambitious reduction target.

Other carbon dioxide emission reduction targets, such as no increase from 1988 emission levels, could be used for the analysis. Any target that is less ambitious than the Toronto Climate Conference target can be evaluated directly from the results presented here. It simply means selecting a smaller number of carbon dioxide emission abatement measures, because the target reduction is smaller.

It should be recognized that achievement of the Toronto Climate Conference target would not prevent further climate warming. The

cumulative impact of past emissions will cause additional warming for many years yet.

### 3.1.2 Calculation of the Emissions Reduction Target

Calculation of the Toronto Climate Conference carbon dioxide emission reduction target is shown in Exhibit 3.1. The basis for the calculation is the national energy supply/demand forecast prepared by the Department of Energy, Mines and Resources using its Inter-Fuel Substitution Demand (IFSD) model.[8] The forecast used is based on Texas crude oil prices rising from U.S. $15 per barrel in 1988 to US $24 per barrel in 2005 (both in 1986 U.S. dollars).

Carbon dioxide emissions due to fossil fuel combustion as estimated from the IFSD forecast amount to roughly 419 million tonnes annually in 1988. Projected emissions of carbon dioxide from fossil fuel combustion based on the model's forecast of energy use in 2005 are 627 million tonnes annually. The Toronto Climate Conference target for carbon dioxide emissions from fossil fuel combustion in 2005 is 80 percent of the 1988 emissions, approximately 336 million tonnes.

To achieve the Toronto Climate Conference target, the projected 2005 emissions must be reduced from 627 to 336 million tonnes; a reduction of 291 million tonnes.

The energy demand forecast by the IFSD model for 2005 probably incorporates some improvement in energy efficiency. The extent of the energy efficiency gains is implicit in the model and can not be easily estimated. To adjust for these implicit energy efficiency improvements, the carbon dioxide reduction target is

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[8] For a description of the forecast see "Long-Term Energy Outlook 1987-2005", Energy Market Analysis Division, Energy, Mines and Resources Canada, June 1988.

EXHIBIT 3.1: PROJECTED CARBON DIOXIDE EMISSIONS AND TORONTO CLIMATE CONFERENCE EMISSIONS REDUCTION TARGET

$CO_2$ EMISSIONS ESTIMATED FROM IFSD
15 - 24 FORECAST

(Millions of Tonnes of $CO_2$ Annually)

| | 1988 | 2005 | Growth 1988-2005 |
|---|---|---|---|
| Residential Sector | 53 (13%) | 61 (10%) | 15% |
| Commercial Sector | 32 ( 8%) | 49 ( 8%) | 53% |
| Industrial Sector | 121 (29%) | 163 (26%) | 35% |
| Transportation Sector | 128 (30%) | 180 (29%) | 41% |
| Electricity Generation | 85 (20%) | 174 (28%) | 104% |
| TOTAL | 419 (100%) | 627 (100%) | 49% |

Toronto Climate Conference Target 80% of 1988 = 336

Apparent reduction needed to achieve the Toronto Climate Conference target = 291 million tonnes of $CO_2$ annually.

Adjustment for possible energy efficiency gains implicit in the IFSD demand forecast = 51 million tonnes of $CO_2$ annually.

Carbon dioxide reduction needed to achieve the Toronto Climate Conference target = 291 to 342 million tonnes of $CO_2$ annually.

expressed as a range. Specifically, it is assumed that the carbon dioxide emissions reduction that would be achieved under the market penetration scenario (51 million tonnes per year) might already be reflected in the IFSD energy forecast. To offset for this implicit reduction, carbon dioxide abatement measures yielding a cumulative emissions reduction of 291 to 342 million tonnes per year must be implemented to meet the target.

## 3.2 Carbon Dioxide Emission Reduction Potential

### 3.2.1 Selection Criteria

A large number of possible carbon dioxide abatement measures are evaluated in Appendix E. The measures selected to help achieve the Toronto Climate Conference target are chosen on the basis of their cost-effectiveness. Measures are selected in order of increasing cost per kilogram of carbon dioxide emissions avoided. Many of the measures have a negative cost per unit reduction of carbon dioxide. This means that the measure yields a net economic benefit to society over its lifetime as a result of energy cost savings, as well as lowering carbon dioxide emissions.[9]

### 3.2.2 Process for Selecting Carbon Dioxide Emission Reduction Measures

Selection of measures to achieve the Toronto Climate Conference target proceeds in three stages:

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[9] In the economic evaluation of carbon dioxide abatement measures, no value has been assigned to the lower emissions. Thus, the true benefits to society are underestimated.

- direct reduction on carbon dioxide emissions through conservation, substitution and other measures that affect fossil fuel use in the residential, commercial, industrial and transportation sectors.

- indirect reduction fo carbon dioxide through measures that affect the use of electricity in the residential, commercial, industrial and transportation sectors. Reduced demand for electricity lowers the use of fossil fuel used to generate electricity and so lowers carbon dioxide emissions.

- Substitution of non-fossil generation for fossil fueled generation. This lowers carbon dioxide emissions by reducing the amount of fossil fuel used to generate electricity.

These three categories of carbon dioxide emissions reductions measures are analysed in turn.

## 3.3 Direct Reduction of Carbon Dioxide Emissions

### 3.3.1 Technical Potential for Direct Carbon Dioxide Emission Reductions

The technical potential to reduce direct carbon dioxide emissions includes all possible measures to lower direct emissions, regardless of cost-effectiveness, but without duplication. For example, a number of alternative fuels are considered in the transportation sector. Ultimately the fuel needs of a given vehicle are supplied by a single fuel. Hence the contributions of alternative fuels must be calculated in a manner that avoids double counting.

The measures selected as offering technical potential for direct reduction of carbon dioxide emissions are listed in Exhibit 3.2.

## EXHIBIT 3.2: DIRECT CARBON DIOXIDE EMISSIONS REDUCTION MEASURES

| | Description of Measure | Percent Energy Savings | Net Measure Cost ($ 1,000,000) | Technical Potential | MEAS Potential | Market Penetration | Technical CO2 Saved (10^6 KG/YR) | MEAS CO2 Saved (10^6 KG/YR) | Ma Market CO2 Saved (10^6 KG/YR) |
|---|---|---|---|---|---|---|---|---|---|
| *1. RESIDENTIAL* | | | | | | | | | |
| R10.3 | Space heating - direct thermal use of solar energy; new housing | 40.0% | (6,794) | 1,862,768 | 80% | 31% | 4,968 | 3,974 | 1,242 |
| R19. | Space heating - oil - substitute high efficiency gas furnace | 25.0% | (646) | 270,000 | 40% | 63% | 887 | 355 | 222 |
| R10.2 | Space heating - direct thermal use of solar energy; new housing | 40.0% | (1,844) | 809,899 | 80% | 31% | 1,461 | 1,169 | 365 |
| R16. | Space heating - oil - energy efficient new housing | 35.0% | (914) | 809,899 | 85% | 29% | 1,890 | 1,607 | 473 |
| R17. | Space heating - oil - increased burner efficiency | 20.0% | (435) | 539,899 | 80% | 31% | 720 | 576 | 180 |
| R27. | Water heating - oil - tank insulation/line | 20.0% | (144) | 404,950 | 60% | 42% | 118 | 71 | 30 |
| R18. | Space heating - oil - retrofit building envelope/ventilation/control | 25.0% | (228) | 809,899 | 60% | 42% | 1,350 | 810 | 338 |
| R13. | Space heating - gas - increased burner efficiency | 20.0% | (426) | 1,862,768 | 80% | 31% | 1,681 | 1,345 | 420 |
| R24. | Water heating - gas - tank insulation/line insulation | 20.0% | (679) | 3,320,586 | 60% | 42% | 657 | 394 | 164 |
| R12. | Space heating - gas - energy efficient new housing | 35.0% | 129 | 1,862,768 | 0% | 0% | 2,942 | 0 | 0 |
| R26. | Water heating - oil - improved burner efficiency | 25.0% | 71 | 404,950 | 0% | 0% | 148 | 0 | 0 |
| R23. | Water heating - gas - improved burner efficiency | 20.0% | 904 | 3,320,586 | 0% | 0% | 657 | 0 | 0 |
| R14. | Space heating - gas - retrofit building envelope/ventilation/control | 25.0% | 907 | 1,862,768 | 0% | 0% | 2,101 | 0 | 0 |

## EXHIBIT 3.2: DIRECT CARBON DIOXIDE EMISSIONS REDUCTION MEASURES (Continued)

| | Description of Measure | Percent Energy Savings | Net Measure Costs ($ 1,000,000) | Technical Potential | MEAS Potential | Market Penetration | Technical CO2 Saved | MEAS CO2 Saved | Market CO2 Saved |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | (10^6 KG/YR) | | |
| *2. MULTI-UNIT RESIDENTIAL* | | | | | | | | | |
| MR11.1 | Space heating - direct thermal use of solar energy; new buildings | 50.0% | (1,851) | 941,323 | 80% | 31% | 1,697 | 1,358 | 424 |
| MR11.1 | Space heating - direct thermal use of solar energy; new buildings | 50.0% | (1,193) | 321,963 | 80% | 31% | 858 | 686 | 214 |
| MR8. | Space heating - gas - energy efficient new buildings | 35.0% | (806) | 941,323 | 80% | 31% | 1,188 | 950 | 297 |
| MR9. | Space heating - oil - energy efficient new buildings | 35.0% | (668) | 321,963 | 80% | 31% | 601 | 480 | 150 |
| MR4. | Space heating - gas - increased plant efficiency/cogeneration | 15.0% | (418) | 627,549 | 40% | 63% | 339 | 136 | 85 |
| MR14. | Water heating - gas - tank insulation, burner efficiency | 25.0% | (360) | 1,686,538 | 60% | 42% | 334 | 200 | 83 |
| MR7. | Space heating - oil - substitute high efficiency gas furnace | 16.0% | (294) | 73,214 | 40% | 63% | 169 | 67 | 42 |
| MR2. | Space heating - oil - retrofit building envelope/ventilation/control | 20.0% | (207) | 219,642 | 60% | 42% | 234 | 140 | 59 |
| MR5. | Space heating - oil - increased plant efficiency/cogeneration | 15.0% | (171) | 146,428 | 40% | 63% | 117 | 47 | 29 |
| MR1. | Space heating - gas - retrofit building envelope/ventilation/control | 20.0% | (155) | 627,549 | 60% | 42% | 453 | 272 | 113 |
| MR13. | Water heating - oil - tank insulation, burner efficiency | 15.0% | (77) | 345,496 | 60% | 42% | 61 | 36 | 15 |
| MR24. | Space Heating - Slowpoke Nuclear | 95.0% | (25) | 3,750 | 20% | 100% | 24 | 5 | 5 |
| MR15. | Water heating - direct thermal use of solar energy | 50.0% | (1) | 4,236 | 60% | 42% | 2 | 1 | 1 |
| MR12. | Space heating - district heating; new buildings | 15.0% | (1) | 3,750 | 70% | 36% | 3 | 2 | 1 |
| MR16. | Water heating - district heating | 15.0% | 2 | 3,750 | 0% | 100% | 1 | 0 | 0 |

## EXHIBIT 3.2: DIRECT CARBON DIOXIDE EMISSIONS REDUCTION MEASURES (Continued)

| | Description of Measure | Percent Energy Savings | Net Measure Costs ($ 1,000,000) | Technical Potential | MEAS Potential | Market Penetration | Technical CO2 Saved (10^3 KG/YR) | MEAS CO2 Saved (10^3 KG/YR) | Ma Market CO2 Saved (10^3 KG/YR) |
|---|---|---|---|---|---|---|---|---|---|
| *3. COMMERCIAL* | | | | | | | | | |
| C11.2 | Space heating - direct thermal use of solar energy; new buildings | 50.0% | (10,504) | 377,593,220 | 80% | 31% | 8,310,714 | 6,648,571 | 2,077,678 |
| C11.1 | Space heating - direct thermal use of solar energy; new buildings | 50.0% | (3,047) | 62,135,593 | 80% | 31% | 2,021,516 | 1,617,213 | 505,379 |
| C4. | Space heating - gas - increased plant efficiency/cogeneration | 25.0% | (805) | 251,799,799 | 40% | 63% | 2,771,019 | 1,108,408 | 692,755 |
| C14. | Water heating - gas - tank insulation, burner efficiency | 25.0% | (763) | 593,559,332 | 60% | 42% | 807,330 | 484,398 | 201,832 |
| C9. | Space heating - oil - energy efficient new buildings | 33.6% | (745) | 61,535,593 | 80% | 31% | 1,343,347 | 1,074,677 | 335,837 |
| C7. | Space heating - oil - substitute high efficiency gas furnace | 16.0% | (675) | 13,807,910 | 40% | 63% | 388,085 | 155,234 | 97,021 |
| C5. | Space heating - oil - increased plant efficiency/cogeneration | 30.0% | (505) | 27,615,819 | 40% | 63% | 539,071 | 215,628 | 134,768 |
| C2. | Space heating - oil - retrofit building envelope/ventilation/control | 20.0% | (385) | 41,423,729 | 60% | 42% | 539,071 | 323,443 | 134,768 |
| C13. | Water heating - oil - tank insulation, burner efficiency | 13.6% | (37) | 31,264,407 | 60% | 42% | 34,286 | 20,572 | 8,572 |
| C24. | Space Heating - Slowpoke Nuclear | 100.0% | (22) | 300,000 | 20% | 100% | 21,933 | 4,387 | 4,387 |
| C12. | Space heating - district heating; new buildings | 15.0% | (3) | 300,000 | 70% | 36% | 2,928 | 2,050 | 732 |
| C15. | Water heating - direct thermal use of solar energy | 75.0% | (1) | 300,000 | 60% | 42% | 1,809 | 1,086 | 452 |
| C16. | Water heating - district heating | 15.0% | 1 | 300,000 | 0% | 0% | 362 | 0 | 0 |
| C1. | Space heating - gas - retrofit building envelope/ventilation/control | 17.6% | 142 | 251,799,799 | 0% | 0% | 1,956,013 | 0 | 0 |
| C8. | Space heating - gas - energy efficient new buildings | 34.9% | 501 | 377,593,220 | 0% | 0% | 5,808,231 | 0 | 0 |

## EXHIBIT 3.2: DIRECT CARBON DIOXIDE EMISSIONS REDUCTION MEASURES (Continued)

| | Description of Measure | Percent Energy Savings | Net Measure Costs ($ 1,000,000) | Technical Potential | MEAS Potential | Market Penetration | Technical CO2 Saved (10^6 KG/YR) | MEAS CO2 Saved (10^6 KG/YR) | Market CO2 Saved (10^6 KG/YR) |
|---|---|---|---|---|---|---|---|---|---|
| *4. TRANSPORTATION* | | | | | | | | | |
| T11. | Intra-City Modal Shift (Car to Bus) | 40.0% | (23,336) | 1 | 100% | 20% | 13,729 | 13,729 | 2,746 |
| T22. | Urban Traffic Management - Gasoline | 25.0% | (13,233) | 1 | 100% | 20% | 9,109 | 9,109 | 1,822 |
| T21. | Urban Traffic Management - Deisel | 25.0% | (5,093) | 1 | 100% | 20% | 3,907 | 3,907 | 781 |
| T1. | Airplane Fuel Economy | 29.8% | (2,523) | 1 | 100% | 10% | 2,635 | 2,635 | 264 |
| T12. | Light Truck Fuel Economy | 45.0% | (2,518) | 0.75 | 50% | 60% | 15,278 | 7,639 | 4,583 |
| T20. | Truck Vehicle Improvements | 12.0% | (2,503) | 410,000 | 90% | 33% | 7,399 | 6,659 | 2,220 |
| T8. | High Capacity Trucking Vehicles | 25.0% | (1,592) | 0.25 | 80% | 37% | 460 | 368 | 138 |
| T17. | Rail Electrification | 68.4% | (946) | 1 | 100% | 0% | 5,363 | 5,363 | 0 |
| T19. | Staggered Work Hours | 5.0% | (879) | 1 | 100% | 5% | 605 | 605 | 30 |
| T9. | Improved Vehicle Maintanence - Comme | 15.0% | (696) | 1,500,000 | 80% | 25% | 2,333 | 1,866 | 467 |
| T18. | Staggered Work Hours | 5.0% | (340) | 1 | 100% | 5% | 261 | 261 | 13 |
| T2. | Auto Fuel Economy | 29.8% | (35) | 13,320,000 | 100% | 30% | 15,692 | 15,692 | 4,708 |
| T10. | Improved Vehicle Maintanence - Private | 15.0% | 168 | 13,300,000 | 0% | 0% | 9,401 | 0 | 0 |
| T15. | Propane fuel - commercial car/van | 0.6% | 467 | 150,000 | 0% | 0% | 195 | 0 | 0 |
| T16. | Propane fuel - private car/van | 0.6% | 2,659 | 1,330,000 | 0% | 0% | 785 | 0 | 0 |

## EXHIBIT 3.2: DIRECT CARBON DIOXIDE EMISSIONS REDUCTION MEASURES (Continued)

| | Description of Measure | Percent Energy Savings | Net Measure Costs ($ 1,000,000 ) | Technical Potential | MEAS Potential | Market Penetration | Technical CO2 Saved (10^6 KG/YR) | MEAS CO2 Saved (10^6 KG/YR) | Market CO2 Saved (10^6 KG/YR) |
|---|---|---|---|---|---|---|---|---|---|
| *5. INDUSTRY* | | | | | | | | | |
| 110. | Energy Cascading | 25.0% | (7,264) | 0.7 | 20% | 75% | 8,223 | 1,645 | 1,234 |
| 14. | Cogeneration | -17.6% | (6,861) | 1.0 | 90% | 17% | (9,928) | (8,935) | (1,489) |
| 130. | Industry Specific Process Change | 12.0% | (2,807) | 1.0 | 80% | 19% | 5,639 | 4,511 | 846 |
| 18. | Electric Heat Pumps | 5.4% | (2,242) | 1.0 | 10% | 100% | 2,538 | 254 | 254 |
| 19. | Energy Cascading | 25.0% | (1,910) | 0.7 | 20% | 75% | 3,881 | 776 | 582 |
| 145. | Waste Heat Recovery - Natural Gas | 5.0% | (1,146) | 1.0 | 90% | 17% | 2,352 | 2,117 | 353 |
| 13. | Arc Furnace Processing | 2.2% | (913) | 1.0 | 10% | 100% | 1,034 | 103 | 103 |
| 129. | Industry Specific Process Change | 12.0% | (680) | 1.0 | 80% | 19% | 2,661 | 2,129 | 399 |
| 127. | Induction Heating | 6.1% | (655) | 0.7 | 10% | 100% | 2,007 | 201 | 201 |
| 136. | Insulation & Housekeeping | 2.0% | (650) | 1.0 | 100% | 15% | 941 | 941 | 141 |
| 17. | Electric Heat Pumps | 5.4% | (589) | 1.0 | 10% | 100% | 1,198 | 120 | 120 |
| 16. | Direct Resistance Heating | 1.2% | (498) | 1.0 | 10% | 100% | 564 | 56 | 56 |
| 118. | High Temperture Plasma Processing | 3.5% | (396) | 1.0 | 10% | 100% | 1,645 | 164 | 164 |
| 132. | Infared Processing | 2.7% | (306) | 1.0 | 10% | 100% | 1,269 | 127 | 127 |
| 144. | Waste Heat Recovery - Heavy Fuel Oil | 5.1% | (280) | 1.0 | 90% | 17% | 1,124 | 1,011 | 169 |
| 12. | Arc Furnace Processing | 2.2% | (240) | 1.0 | 10% | 100% | 488 | 49 | 49 |
| 122. | Process Controls & Instrumentation | 1.0% | (229) | 1.0 | 100% | 15% | 470 | 470 | 71 |
| 135. | Insulation & Housekeeping | 2.1% | (153) | 1.0 | 100% | 15% | 459 | 459 | 69 |
| 126. | Induction Heating | 6.1% | (143) | 0.7 | 10% | 100% | 947 | 95 | 95 |
| 15. | Direct Resistance Heating | 1.2% | (131) | 1.0 | 10% | 100% | 266 | 27 | 27 |
| 117. | High Temperture Plasma Processing | 3.5% | (76) | 1.0 | 10% | 100% | 776 | 78 | 78 |
| 141. | Solar Preheating | 6.0% | (75) | 1.0 | 60% | 25% | 2,819 | 1,692 | 423 |
| 121. | Process Controls & Instrumentation | 1.1% | (62) | 1.0 | 100% | 15% | 244 | 244 | 37 |

## EXHIBIT 3.2: DIRECT CARBON DIOXIDE EMISSIONS REDUCTION MEASURES (Continued)

| | Description of Measure | Percent Energy Savings | Net Measure Costs ($ 1,000,000 ) | Technical Potential | MEAS Potential | Market Penetration | Technical CO2 Saved | MEAS CO2 Saved | Market CO2 Saved |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | (10^6 KG/YR) | | |
| *5. INDUSTRY* | | | | | | | | | |
| 131. | Infared Processing | 2.7% | (59) | 1.0 | 10% | 100% | 599 | 60 | 60 |
| 139. | Laser Processing | 0.4% | (45) | 1.0 | 10% | 100% | 188 | 19 | 19 |
| 112. | Energy Cascading Systems | 10.0% | (37) | 0.3 | 30% | 50% | 1,410 | 423 | 211 |
| 11. | Arc Furnace Processing | 2.2% | (33) | 1.0 | 10% | 100% | 135 | 14 | 14 |
| 133. | Insulation & Housekeeping | 2.0% | (16) | 1.0 | 100% | 15% | 121 | 121 | 18 |
| 143. | Waste Heat Recovery - Coal | 5.0% | (11) | 1.0 | 90% | 17% | 309 | 278 | 46 |
| 138. | Laser Processing | 0.4% | (9) | 1.0 | 10% | 100% | 89 | 9 | 9 |
| 119. | Process Controls & Instrumentation | 1.1% | (3) | 1.0 | 100% | 15% | 67 | 67 | 10 |
| 111. | Energy Cascading Systems | 10.0% | 22 | 0.3 | 0% | 0% | 665 | 0 | 0 |
| 123. | Process Controls & Instrumentation | 1.0% | 43 | 1.0 | 0% | 0% | 397 | 0 | 0 |
| 140. | Solar Preheating | 6.0% | 44 | 1.0 | 0% | 0% | 1,331 | 0 | 0 |
| 137. | Insulation & Housekeeping | 2.0% | 86 | 1.0 | 0% | 0% | 793 | 0 | 0 |
| 146. | Waste Heat Recovery - Wood | 5.0% | 399 | 1.0 | 0% | 0% | 1,983 | 0 | 0 |
| 113. | Energy from Waste | -33.3% | ERR | 1.0 | 0% | 0% | ERR | ERR | ERR |

This list excludes demand-side management measures and other measures that only affect the demand for electricity. Those measures are addressed in the next section. The exhibit also excludes measures related to electricity generation which are discussed later.

The exhibit provides, for each measure selected, a short description of the measure, the estimated energy savings (as a percentage), the aggregate net measure cost for installing the measure in all feasible applications, the technical potential for the measure in terms of the number of typical units and total carbon dioxide reduction that can be achieved by the measure. The data are drawn from Appendix E. The measures are listed within each sector starting with the most cost-effective and continuing until the technical potential has been exhausted.

Where appropriate, energy savings and emission reductions have been adjusted to reflect interactive effects with other measures. For example, the impact of improved automobile tuning has been adjusted to reflect the greater fuel efficiency of new automobiles. The improved fuel efficiency means that the benefits of better tuning are reduced.

### 3.3.2 Measures Economically Attractive to Society

Measures economically attractive to society (MEAS) differs from the technical potential in two ways. First, a measure that is not economically attractive to society may be included in the technical potential, but it is not included in the MEAS. Second, a measure that is economically attractive to society may have a lower penetration under the MEAS than under the technical potential.

The measures economically attractive to society for direct reduction of carbon dioxide emissions are also identified in

Exhibit 3.2. The exhibit shows the MEAS penetration as a percentage of the technical potential and the carbon dioxide emission reductions associated with each of those measures. Measures with a net measure cost greater than zero are excluded from MEAS because they are, by definition, not economically attractive to society.

In principle, the economic potential of a measure that is economically attractive to society is equal to the technical potential of that measure. However, the MEAS penetration is often adjusted to be less than the technical potential. The reason is that while the measure is economically attractive on average, it may not be economically attractive in all applications. For example, building envelope retrofits may be attractive on average, but are not justified for buildings nearing the end of their useful lives.

### 3.3.3 Market Penetration

Market penetration is the penetration each measure is likely to achieve with no new policies, incentives, or regulations. The market penetration estimates are based on the literature and judgements reflecting the economic attractiveness of measures.

Market potential is generally much less than the technical potential and the penetration of measures economically attractive to society. This is because firms and individuals tend to seek much higher returns from energy investments than the social discount rate. A real discount rate of 7 percent per year may be appropriate from society's perspective. But research indicates that individuals and businesses often require real returns well over 25 percent (indeed over 100 percent) per year for energy investments. Market penetration can also be hampered by a variety of institutional and other barriers.

Market penetration is also shown in Exhibit 3.2 in terms of the percentage of technical potential for each measure and the associated carbon dioxide emissions reductions.

### 3.3.4 Direct Carbon Dioxide Emissions Reductions

The estimated carbon dioxide emissions reductions achievable in relation to fossil fuel use in the end use sectors by 2005 are summarized in Exhibit 3.3.

#### Technical Potential

The technical potential of 177 million tonnes is not enough to achieve the Toronto Climate Conference target. However, measures that reduce the demand for electricity and the substitution of non-fossil generation for fossil fueled generation are not yet reflected in the estimates.

The technical potential of 177 million tonnes of carbon dioxide represents almost 40 percent of the estimated emissions by the end use sectors. The estimates of technical potential for carbon dioxide emissions reductions agree closely with those of a recent American study. That study estimated the technical potential for buildings at 50 percent, for industry at 25 percent and for the transportation sector at 50 percent as well.[10]

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10 It estimates the technical potential at 25% for existing houses and 50% for new houses, since the two stocks are roughly equal by 2005 this amounts to 37.5% for the sector. In the commercial sector the estimates are 50% for existing stock and 75% for new stock. Since new stock is 60% of the total by 2005 that amounts to 65% for the commercial sector. Based on the energy use in the residential and commercial sectors in 2005, the overall target becomes 50%. The technical potential for the industrial sector was estimated at 25% and for the transportation sector was estimated at 50%.

EXHIBIT 3.3: ESTIMATED DIRECT CARBON DIOXIDE EMISSION REDUCTIONS ACHIEVABLE[1]

(Millions of Tonnes Annually By 2005)

| | Market Penetration | Measures Economically Attractive to Society[3] | Technical Potential[2] | Technical Potential as a Share of 2005 $CO_2$ Emissions from the Sector |
|---|---|---|---|---|
| Residential | 3 | 10 | 20 | 45% |
| Multi-Residential | 2 | 4 | 6 | |
| Commercial | 4 | 12 | 25 | |
| Industrial | 5 | 9 | 40 | 24% |
| Transportation | 18 | 68 | 87 | 49% |
| TOTAL | 31 | 103 | 177 | 39% |

Notes: 1) The reductions shown relate only to fossil fuel use in the sector.

2) Technical potential includes all measures that can be implemented in a sector to reduce direct carbon dioxide emissions. Measures that are economically attractive from society's perspective are selected first. Potential overlap of measures has been eliminated.

3) Includes measures that are economically attractive from society's perspective and that form part of the technical potential. The penetration estimated for these measures is sometimes lower than in the estimate of technical potential.

Almost half of the total reduction in carbon dioxide emissions is estimated to be able to come from the transportation sector. The principal sources of these savings are improved fuel economy for automobiles, light trucks and heavy trucks (38 million tonnes of $CO_2$ annually) and improved urban traffic management including increased use of carbon public transit (27 million tonnes of $CO_2$ annually).

Measures Economically Attractive to Society

The reduction in carbon dioxide emissions achieved through implementation of measures economically attractive to society (MEAS) is estimated at 103 million tonnes of carbon dioxide annually. This is roughly 60 percent of the technical potential.

The MEAS carbon dioxide emission reductions for the buildings sector is half the reduction estimated to be technically feasible. The principal reason for the difference is that several of the measures that are technically feasible are not economically attractive from society's perspective and so are excluded from the MEAS estimate.

The reduction in carbon dioxide emissions for the industrial sector appears to be much lower under MEAS than under the technical potential (9 vs 40 million tonnes of carbon dioxide annually). This is deceptive. The technical potential includes a number of electrotechnologies which use electricity to displace fossil fuels. The emissions eliminated by displacing the fossil fuels are reflected in the figures presented in Exhibit 3.3 but the emissions associated with generating the additional electricity are not. The electricity demand is analysed separately in the next section. The MEAS estimate does not include all of the same electrotechnologies. Because of the continued fossil fuel use when these technologies are not adopted, the reduction in direct carbon dioxide emissions is

lower but the net reduction in electricity demand, as will be seen in the next section, is higher.

The difference between the technical potential and MEAS estimate in the transportation sector is largely accounted for by propane use in private automobiles. This is technically feasible but not economic on a large scale. Transportation fuels are compared on the basis of prices net of federal and provincial taxes. Without tax advantages, alternative transportation fuels are not competitive with gasoline.

Market Penetration

Market penetration yields a reduction of roughly 31 million tonnes of carbon dioxide emissions by 2005; about 18 percent of the technical potential. The carbon dioxide emissions reductions are between 10 and 20 percent of the technical potential in all sectors.

## 3.4 Measures that Affect the Demand for Electricity

### 3.4.1 Nature of the Impacts on the Demand for Electricity

Some of the measures identified affect the demand for electricity. The effects are felt in one of three ways:

- demand side management measures reduce the demand for electricity;
- electrotechnologies in the industrial sector substitute processes that use electricity for ones that use fossil fuel and so increase the demand for electricity; and
- cogeneration or by-product electricity increases the supply of electricity.

The net impact of measures that affect the supply of, or demand for, electricity is considered in this section.

### 3.4.2 Technical Potential of Measures that Affect Electricity Demand

The measures selected that have an impact on the demand for electricity are listed in Exhibit 3.4. The exhibit provides the same information for each measure as was provided earlier for the direct emission reduction measures with the exception that the carbon dioxide emissions reductions are replaced by the electricity savings. Additional information on the measures is provided in Appendix E.

The industrial sector includes a number of electrotechnologies that increase the demand for electricity (they are shown as negative savings), as well as measures that reduce the demand for electricity and co-generation which produces electricity. The transportation sector produces a small net increase in electricity use as a result of rail electrification.

The demand-side management measures were evaluated using the price of electricity. This is based on the historical average cost. Utilities evaluate such demand-side management measures using marginal or avoided costs. The marginal or avoided cost could be higher or lower than the price of electricity. The avoided cost depends on the utility's need for additional capacity and the impact of the measure on peak and off-peak demand.

Financial incentives are sometimes offered by utilities to promote adoption of demand-side management measures. Such incentives have not been considered in this analysis. Due to the differences in approach noted above, electric utilities may

## EXHIBIT 3.4: MEASURES THAT AFFECT THE DEMAND FOR ELECTRICITY

| | Description of Measure | Percent Energy Savings | Net Measure Cost ($ 1,000,000) | Technical Potential | MEAS Potential | Market Penetration | Technical Electricity Saved (GJ/YR) | MEAS Electricity Saved (GJ/YR) | Market Electricity Saved (GJ/YR) |
|---|---|---|---|---|---|---|---|---|---|
| *1. RESIDENTIAL* | | | | | | | | | |
| R5. | Demand Management - Electric Space Heating - thermally activated heat pump | 35.0% | (4,966) | 2,105,738 | 60% | 42% | 43,704,003 | 26,222,402 | 10,926,001 |
| R10.1 | Space heating - direct thermal use of solar energy; new housing | 40.0% | (4,596) | 1,376,828 | 80% | 31% | 32,657,920 | 26,126,336 | 8,164,480 |
| R6. | Demand Management - Electric Water Heating - tank insulation/line | 55.0% | (4,451) | 4,211,475 | 60% | 42% | 30,111,120 | 18,066,672 | 7,527,780 |
| R2. | Demand Management - Appliances and fixtures - improved efficiency | 15.0% | (1,152) | 8,098,990 | 60% | 42% | 15,792,545 | 9,475,527 | 3,948,136 |
| R3. | Demand Management - Electric Space Heating - energy efficient new housing | 35.0% | (904) | 1,052,869 | 85% | 29% | 21,852,001 | 18,574,201 | 5,463,000 |
| R15. | Space heating - heat pump - energy efficient new housing | 35.0% | (440) | 323,960 | 60% | 42% | 6,723,699 | 4,034,219 | 1,680,925 |
| R4. | Demand Management - Electric Space Heating - envelope retrofit | 25.0% | (340) | 1,052,869 | 60% | 42% | 15,608,572 | 9,365,143 | 3,902,143 |
| R1. | Demand Management - Air conditioning - improved efficiency | 10.0% | 590 | 1,700,788 | 0% | 0% | 967,408 | 0 | 0 |
| R21. | Water heating - direct thermal use of solar energy | 60.0% | 329 | 161,980 | 0% | 0% | 1,263,405 | 0 | 0 |

## EXHIBIT 3.4: MEASURES THAT AFFECT THE DEMAND FOR ELECTRICITY (Continued)

| | Description of Measure | Percent Energy Savings | Net Measure Costs ($ 1,000,000) | Technical Potential | MEAS Potential | Market Penetration | Technical Electricity Saved | MEAS Electricity Saved | Market Electricity Saved |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | (GJ/YR) | | |
| *2. MULTI-UNIT RESIDENTIAL* | | | | | | | | | |
| MR22. | Demand Management - Lighting - high efficiency lighting | 75.0% | (4,635) | 3,922,181 | 80% | 31% | 33,534,648 | 26,827,718 | 8,383,662 |
| MR19. | Demand Management - Air conditioning - improve efficiency | 20.5% | (1,161) | 823,658 | 90% | 28% | 7,984,268 | 7,185,841 | 1,996,067 |
| MR20. | Demand Management - Electric Space Heating - retrofit insulation | 15.1% | (727) | 690,304 | 60% | 42% | 4,942,870 | 2,965,722 | 1,235,718 |
| MR21. | Demand Management - Electric Space Heating - energy efficient new buildings | 20.0% | (633) | 517,728 | 80% | 31% | 4,908,061 | 3,926,449 | 1,227,015 |
| MR23. | Demand Management - Phase loading, load control and power factor control | 5.0% | (601) | 3,922,181 | 80% | 31% | 3,726,072 | 2,980,858 | 931,518 |
| MR18. | Demand Management - Electric Equipment - improved motor efficiency | 10.0% | (596) | 3,922,181 | 90% | 28% | 4,079,068 | 3,671,161 | 1,019,767 |
| MR17. | Water heating - heat pump water heaters | 20.0% | 41 | 564,794 | 0% | 0% | 1,174,772 | 0 | 0 |

## EXHIBIT 3.4: MEASURES THAT AFFECT THE DEMAND FOR ELECTRICITY (Continued)

| | Description of Measure | Percent Energy Savings | Net Measure Costs ($ 1,000,000) | Technical Potential | MEAS Potential | Market Penetration | Technical Electricity Saved | MEAS Electricity Saved | Market Electricity Saved |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | (GJ/YR) | | |
| *3. COMMERCIAL* | | | | | | | | | |
| C22. | Demand Management - Lighting - high efficiency lighting | 75.0% | (21,120) | 796,610,169 | 80% | 31% | 179,237,288 | 143,389,831 | 44,809,322 |
| C23. | Demand Management - Phase loading, load control and power factor control | 4.3% | (4,292) | 796,610,169 | 80% | 31% | 24,922,518 | 19,938,015 | 6,230,630 |
| C18. | Demand Management - Electric Equipment - improved motor efficiency | 25.0% | (2,850) | 796,610,169 | 90% | 28% | 67,711,864 | 60,940,678 | 16,927,966 |
| C11.3 | Space heating - direct thermal use of solar energy; new buildings | 50.0% | (2,209) | 38,237,288 | 80% | 31% | 11,088,814 | 8,871,051 | 2,772,203 |
| C19. | Demand Management - Air conditioning - improve efficiency | 20.5% | (413) | 637,288,136 | 90% | 28% | 11,729,735 | 10,556,761 | 2,932,434 |
| C21. | Demand Management - Electric Space Heating - energy efficient new buildings | 20.0% | (244) | 19,118,644 | 80% | 31% | 2,217,763 | 1,774,210 | 554,441 |
| C20. | Demand Management - Electric Space Heating - retrofit insulation | 15.1% | (79) | 25,491,525 | 60% | 42% | 2,233,492 | 1,340,095 | 558,373 |
| C17. | Water heating - heat pump water heaters | 40.0% | 194 | 57,379,594 | 0% | 0% | 1,606,629 | 0 | 0 |
| C10. | Space heating - heat pump - energy efficient new buildings | 40.0% | 1,393 | 19,118,644 | 0% | 0% | 4,435,525 | 0 | 0 |

| | Description of Measure | Percent Energy Savings | Net Measure Costs ($1,000,000) | Technical Potential | MEAS Potential | Market Penetration | Technical Electricity Saved | MEAS Electricity Saved | Market Electricity Saved |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | (GJ/YR) | | |
| *4. TRANSPORTATION* | | | | | | | | | |
| T17. | Rail Electrification | 68.4% | (946) | 1 | 100% | 0% | (24,000,000) | (24,000,000) | 0 |

## EXHIBIT 3.4: MEASURES THAT AFFECT THE DEMAND FOR ELECTRICITY (Continued)

| | Description of Measure | Percent Energy Savings | Net Measure Costs ($ 1,000,000 ) | Technical Potential | MEAS Potential | Market Penetration | Technical Electricity Saved (GJ/YR) | MEAS Electricity Saved (GJ/YR) | Market Electricity Saved (GJ/YR) |
|---|---|---|---|---|---|---|---|---|---|
| *5. INDUSTRY* | | | | | | | | | |
| 14. | Cogeneration | -17.6% | (6,861) | 1.0 | 90% | 17% | 170,689,180 | 153,620,262 | 25,603,377 |
| 128. | Industry Specific Process Change | 12.0% | (5,912) | 1.0 | 30% | 50% | 126,440,855 | 37,932,257 | 18,966,128 |
| 114. | Energy-efficient Lighting | 4.1% | (3,410) | 1.0 | 80% | 19% | 43,190,052 | 34,552,042 | 6,478,508 |
| 18. | Electric Heat Pumps | 5.4% | (2,242) | 1.0 | 10% | 100% | (20,000,628) | (2,000,063) | (2,000,063) |
| 134. | Insulation & Housekeeping | 2.3% | (1,763) | 1.0 | 100% | 15% | 23,845,278 | 23,845,278 | 3,576,792 |
| 13. | Arc Furnace Processing | 2.2% | (913) | 1.0 | 10% | 100% | (4,000,126) | (400,013) | (400,013) |
| 127. | Induction Heating | 6.1% | (655) | 0.7 | 10% | 100% | (35,934,462) | (3,593,446) | (3,593,446) |
| 17. | Electric Heat Pumps | 5.4% | (589) | 1.0 | 10% | 100% | (2,666,750) | (266,675) | (266,675) |
| 115. | Energy-efficient Motors & Motor Drives | 4.1% | (523) | 1.0 | 90% | 17% | 43,190,052 | 38,871,047 | 6,478,508 |
| 16. | Direct Resistance Heating | 1.2% | (498) | 1.0 | 10% | 100% | (1,333,375) | (133,338) | (133,338) |
| 142. | Waste Heat Recovery | 2.1% | (464) | 1.0 | 90% | 17% | 22,138,387 | 19,924,548 | 3,320,758 |
| 118. | High Temperture Plasma Processing | 3.5% | (396) | 1.0 | 10% | 100% | (24,667,441) | (2,466,744) | (2,466,744) |
| 132. | Infared Processing | 2.7% | (306) | 1.0 | 10% | 100% | (49,334,882) | (4,933,488) | (4,933,488) |
| 120. | Process Controls & Instrumentation | 1.1% | (243) | 1.0 | 100% | 15% | 11,612,554 | 11,612,554 | 1,741,883 |
| 12. | Arc Furnace Processing | 2.2% | (240) | 1.0 | 10% | 100% | (1,200,038) | (120,004) | (120,004) |
| 126. | Induction Heating | 6.1% | (143) | 0.7 | 10% | 100% | (6,066,857) | (606,686) | (606,686) |
| 116. | Energy-efficient Refrigeration | 0.6% | (133) | 1.0 | 90% | 17% | 6,349,638 | 5,714,674 | 952,446 |
| 15. | Direct Resistance Heating | 1.2% | (131) | 1.0 | 10% | 100% | (8,000,251) | (800,025) | (800,025) |
| 117. | High Temperture Plasma Processing | 3.5% | (76) | 1.0 | 10% | 100% | (4,666,813) | (466,681) | (466,681) |
| 131. | Infared Processing | 2.7% | (59) | 1.0 | 10% | 100% | (8,666,939) | (866,694) | (866,694) |
| 139. | Laser Processing | 0.4% | (45) | 1.0 | 10% | 100% | (13,333,752) | (1,333,375) | (1,333,375) |
| 11. | Arc Furnace Processing | 2.2% | (33) | 1.0 | 10% | 100% | (666,688) | (66,669) | (66,669) |
| 138. | Laser Processing | 0.4% | (9) | 1.0 | 10% | 100% | (2,000,063) | (200,006) | (200,006) |

arrive at very different estimates of the potential for electrical efficiency improvements than those presented here.

### 3.4.3 Measures Economically Attractive to Society and Market Penetration

The measures that affect the demand for electricity and are economically attractive to society are also identified in Exhibit 3.4. Again measures that are part of the technical potential, but which have a positive net measure cost are excluded. As well, the penetration level is often adjusted from that estimated as being technically feasible.

The market penetration of measures that affect the demand for electricity is also shown in Exhibit 3.4. The market penetration is estimated in the same manner as outlined for measures that affect direct emissions of carbon dioxide.

### 3.4.4 Reductions in the Demand for Electricity

The estimated reductions that can be achieved in the demand for electricity are summarized in Exhibit 3.5.

The technical potential is slightly greater than the forecast growth in demand for electricity. The technical potential amounts to a 25 percent reduction in the forecast demand for electricity in the industrial sector and a 46 percent reduction in the demand forecast for the combined residential and commercial sectors. Commercial buildings, including multi-residential buildings, contribute almost half of the total reduction in demand for electricity under the technical potential scenario.

The MEAS estimate for the industrial sector is larger than the technical potential. This reflects the role of

EXHIBIT 3.5: ESTIMATED REDUCTIONS IN DEMAND FOR ELECTRICITY ACHIEVABLE

(PJ Annually By 2005)

| | Market Penetration | Measures Economically Attractive to Society | Technical Potential | Technical Potential as % of Forecast 2005 Demand in the Sector |
|---|---|---|---|---|
| Residential | 33 | 86 | 169 | |
| Multi-Residential | 23 | 71 | 92 | 46% |
| Commercial | 75 | 247 | 301 | |
| Industrial | 49 | 308 | 265 | 25% |
| Transport | Nil | -24 | -24 | |
| TOTAL SAVINGS | 180 | 688 | 803 | 35% |
| Projected growth in secondary demand for electricity from IFSD | 794 | 794 | 794 | |

electrotechnologies discussed previously. The MEAS scenario assumes lower penetration of electrotechnologies and larger savings in the demand for electricity than the technical potential case.

The market penetration case yields reductions in demand for electricity of approximately 180 PJ annually. This represents just over 22 percent of the forecast growth in demand for electricity over the period to 2005.

### 3.4.5 Comparison with Other Estimates of Technical Potential for Demand-Side Management Measures

The estimated potential for demand-side management measures is consistent with the findings of a recent New York study.[11] The New York study estimated the technical potential for electricity conservation at approximately 30 percent of current demand. The somewhat higher (35 percent) estimate of technical potential estimated here is not inconsistent in that it applies to future demand. Further technological developments and the ability to implement measures in new buildings and equipment argue for higher savings relative to future demand. The savings estimated for the measures economically attractive to society amount to 30 percent of forecast demand.

Ontario Hydro has established demand management targets of 4,500 MW (peak) by 2000. The targets include 1,000 MW of load shifting and 3,500 MW of efficiency improvements. The total

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11 American Council for an Energy Efficient Economy, "The Potential for Electricity Conservation in New York State", New York State Energy Research and Development Authority, review draft, February, 1989. The study estimated the potential for conservation at approximately 30% of current demand. A somewhat higher, say 35%, reduction of forecast demand is not unreasonable.

represents just over 15 percent of the projected peak load in 2000. The industrial sector and commercial sector targets are each 38 percent of the Ontario Hydro's total target.

### 3.4.6 Electricity Generation and Carbon Dioxide Emissions

The results summarized in Exhibit 3.5 indicate that part or all of the forecast growth in demand for electricity can be averted through the measures identified. Additional generation capacity is needed to supply the remaining growth in demand for electricity.

The IFSD model develops a specific mix of new generating capacity to supply its forecast growth in the demand for electricity. Use of that mix of capacity to meet the forecast growth in demand for electricity raises estimated carbon dioxide emissions from 85 to 174 million tonnes annually between 1988 and 2005.[12] Reducing the demand for electricity allows a portion of this 88 million tonne increase in annual carbon dioxide emissions to be avoided. That amount is calculated below.

### 3.4.7 Primary Fuel Use for Electricity Generation

The carbon dioxide emissions for electricity generation are a function of the primary fuel use. To translate the reductions in secondary demand for electricity into reduced carbon dioxide emissions, they must first be converted to primary fuel demands. That is done in Exhibit 3.6.

The growth in secondary demand for electricity as forecast by the IFSD model is 794 PJ. That figure is reduced by the estimated reduction in secondary demand for electricity as summarized in Exhibit 3.5. A revised forecast of growth in secondary demand

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12 See Exhibit 3.1.

EXHIBIT 3.6: REDUCTIONS IN CARBON DIOXIDE EMISSIONS DUE TO LOWER DEMAND FOR ELECTRICITY

| | Market Penetration | Measures Economically Attractive to Society | Technical Potential |
|---|---|---|---|
| Projected growth in secondary demand for electricity from IFSD (PJ) | 794 | 794 | 794 |
| Estimated reductions in demand for electricity from Exhibit 3.5 (PJ) | 180 | 688 | 803 |
| Revised forecast of growth in secondary demand for electricity (PJ) | 614 | 106 | Nil |
| Associated transmission losses (9% of secondary demand) (PJ) | 55 | 10 | Nil |
| Electrical output needed from new generating capacity (PJ) | 669 | 116 | Nil |
| Primary energy needed to produce the additional electrical output (PJ of primary energy) | 1,967 | 341 | Nil |
| Capacity additions needed to supply growth in demand for electricity (PJ of primary energy) | | | |
| - coal | 584 | 101 | Nil |
| - other fossil fuel | 140 | 24 | Nil |
| - nuclear | 278 | 48 | Nil |
| - hydro | 965 | 168 | Nil |
| total | 1,967 | 341 | Nil |
| Carbon dioxide emissions associated with this mix of electrical generation (million tonnes) | 68 | 12 | Nil |
| Carbon dioxide emissions due to IFSD forecast of growth in demand for electricity (million tonnes) | 88 | 88 | 88 |
| Carbon dioxide emissions reductions due to lower demand for electricity (million tonnes) | 20 | 76 | 88 |

for electricity to 2005 is calculated. The transmission losses associated with this revised growth in secondary demand are estimated to get the additional electricity that must be supplied.

The electricity supplied is converted to a primary demand. This primary demand is assumed to be met proportionally by the different types of capacity forecast by the IFSD model to be added between 1988 and 2005.[13] The carbon dioxide emissions associated with the required capacity additions are estimated. These are deducted from the estimated growth in carbon dioxide emissions (88 million tonnes) implied by the IFSD model forecast of demand for electricity. The result is the estimated reduction in carbon dioxide emissions due to lower demand for electricity.

### 3.4.8 Reduction in Carbon Dioxide Emissions due to Lower Demand for Electricity

The lower demand for electricity means that the forecast additions to capacity and corresponding use of fossil fuels will

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13 The IFSD model determines the fuels used to generate electricity in 1988 and the fuels forecast to be used to supply the growth in demand to 2005. The amounts of primary fuels needed to meet the demand for electricity are as follows:

| | IFSD Forecast of Primary Fuel Use for Electricity Generation | | |
|---|---|---|---|
| Primary Fuel | 1988 | Additions 1988-2005 | |
| | (PJ) | (PJ) | (%) |
| Coal | 750 | 783 | 29.7 |
| Other fossil fuels | 216 | 187 | 7.1 |
| Nuclear | 877 | 372 | 14.1 |
| Hydro | 3,009 | 1,294 | 49.1 |
| Total | 4,852 | 2,636 | 100.0 |

not be needed. The reduction in demand for electricity and adjusted capacity additions are shown in Exhibit 3.6.

The technical potential eliminates the growth in demand for electricity and so avoids any growth in carbon dioxide emissions for electrical generation, a saving of 88 million tonnes annually.

The reductions for the MEAS and market penetration cases are 76 million tonnes of carbon dioxide and 20 million tonnes of carbon dioxide annually by 2005.

## 3.5 Substitution of Non-Fossil Electricity Generation for Fossil Fueled Generation

As a result of the measures to reduce demand for electricity, some of the additions to non-fossil fueled generation forecast by the IFSD model for the period to 2005 are not needed to meet the growth in demand. This non-fossil generation is, in principle, available to displace projected and existing fossil fueled generation. Other non-fossil generation technologies expected to be viable by 2005, such as photovoltaic, wind, tidal, geothermal, and fuel cells can also be substituted for fossil fueled generation. These possibilities provide a further opportunity to reduce carbon dioxide emissions.

### 3.5.1 Market Penetration Scenario

Substitution of non-fossil generation for fossil fueled generation is not considered for the market penetration case. Rather the market penetration scenario is used as an estimate of the amount of energy efficiency improvement that may be embodied in the IFSD energy forecast. Hence only energy efficiency measures are analysed for the market penetration scenario.

Energy efficiency measures that affect fossil fuel use lead to direct reductions of carbon dioxide emissions of 31 million tonnes per year by 2005. Measures that affect the demand for electricity lead to indirect reductions of carbon dioxide emissions of 20 million tonnes per year by 2005. The direct and indirect carbon dioxide emissions reductions associated with the market penetration measures (51 million tonnes per year) are added to the reduction target to account for the possibility that they may already be implicit in the energy demand forecast.

### 3.5.2 Measures Economically Attractive to Society

The additions to non-fossil electrical generating capacity forecast by the IFSD model for the period 1988 to 2005 amount to 1,666 PJ of primary energy as shown in Exhibit 3.7. The amount of non-fossil fueled generation projected to be needed to supply the revised growth in demand for electricity as estimated in Exhibit 3.6 is 216 PJ of primary energy. That means the non-fossil fuel generating capacity potentially available to displace fossil-fuel generation by 2005 is 1,450 PJ of primary energy.

This latter figure includes only hydro and nuclear capacity forecast by the IFSD model as being potentially available by 2005. It could be increased to incorporate additional non-fossil generation capacity of any type that could be provided by 2005; hydro, nuclear, wind, photovoltaic, fuel cells, tidal, geothermal, etc. But these additions are not needed for the analysis.

The fossil fueled generation capacity needed to supply the revised growth in demand for electricity, as estimated in Exhibit 3.6, is 125 PJ of primary energy. The fossil fueled generation capacity in operation in 1988 was 966 PJ of primary

EXHIBIT 3.7: POTENTIAL CARBON DIOXIDE REDUCTIONS DUE TO REPLACEMENT OF FOSSIL FIRED GENERATION WITH NON-FOSSIL GENERATION

| | Measures Economically Attractive to Society | Technical Potential |
|---|---|---|
| Proposed additions to non-fossil generation capacity 1988-2005 from IFSD (PJ) | | |
| - hydro | 372 | 372 |
| - nuclear | 1,294 | 1,294 |
| - total | 1,666 | 1,666 |
| Estimated non-fossil additions to supply the revised growth in demand for electricity 1988-2005 from Exhibit 3.6 (PJ) | | |
| - hydro | 48 | Nil |
| - nuclear | 168 | Nil |
| - total | 216 | Nil |
| Non-fossil capacity available to displace existing or planned fossil generation capacity (PJ) | 1,450 | 1,666 |
| Fossil fueled capacity additions needed to supply the revised growth in demand for electricity 1988-2005 from Exhibit 3.6 (PJ) | | |
| - coal | 101 | Nil |
| - other fossil | 24 | Nil |
| - total | 125 | Nil |
| Existing (1988) fossil fuel generation capacity from IFSD (PJ) | | |
| - coal | 750 | 750 |
| - other fossil | 216 | 216 |
| - total | 966 | 966 |
| Reduced requirement for fossil fueled generation due to lower demand for electricity (PJ) | Nil | -6 |
| Total fossil fueled capacity expected to be needed to serve revised energy demands (PJ) | 1,091 | 960 |
| Surplus of potentially available non-fossil fueled generation (PJ) | 359 | 706 |
| Carbon dioxide emissions reduction due to reduced need for existing fossil fueled generation (millions of tonnes/yr) | Nil | 0.5 |
| Carbon dioxide emissions reduction due to displacement of new fossil fueled generation (millions of tonnes/year) | 12 | Nil |
| Carbon dioxide emissions reduction due to replacement of existing fossil fueled generation (millions of tonnes) | 30 | 84.5 |
| Total carbon dioxide emissions reduction due to replacement of fossil fueled generation (millions of tonnes/yr) | 42 | 85 |

energy. Thus, the total fossil fueled generation capacity that would be in place by 2005 is 1,091 PJ.

As Exhibit 3.7 shows, a total of 1,450 PJ of non-fossil generation is potentially available to displace this 1,091 PJ of fossil fueled generation. In other, words all proposed and existing fossil fueled generation could be displaced by non-fossil generation without using the non-fossil generation forecast by the IFSD model to be available by 2005.

Carbon Dioxide Emissions Reduction

The carbon dioxide emissions reduction must be considered separately for two situations:

- substitution for new fossil fueled generation; and
- replacement of existing fossil fueled generation.

The 125 PJ of new fossil fueled generation is not yet built. Building an equivalent amount of non-fossil generation imposes no additional economic burden on society. Substituting non-fossil generation for this new fossil fueled generation would avoid any growth in carbon dioxide emissions due to electricity generation. Hence the carbon dioxide emissions reduction is the forecast growth in emissions due to electricity generation (88 million tonnes/yr) less the reduction achieved through improved electrical efficiency (76 million tonnes/yr) or 12 million tonnes per year.

Replacement of all existing fossil fueled generation by new non-fossil generation would reduce the 1988 emissions of carbon dioxide due to electricity generation (85 million tonnes) to zero. Hence, the maximum carbon dioxide emissions reduction potential is 85 million tonnes per year. Many of the existing fossil fuel plants will still be in operation in 2005. Replacing

them before the end of their useful life would impose an economic burden on society. Using a 40 year life for a fossil fueled generating station suggests that roughly 35 percent of the existing capacity will be replaced by 2005. The fossil fueled facilities that need to be replaced can be replaced by non-fossil generation at no net cost to society. Hence the MEAS estimate of the carbon dioxide emissions reduction due to replacement of existing fossil fueled generation is (35% of 85) 30 million tonnes per year.

The total carbon dioxide emissions reduction achievable through measures economically attractive to society is 42 million tonnes per year.

### 3.5.3 Technical Potential

#### Impact of Reduced Demand for Electricity

The technical potential scenario yields a reduction in secondary demand for electricity (803 PJ) that is greater than the forecast growth in secondary demand (794 PJ). The balance (9 PJ), adjusted for transmission losses, represents a primary demand of 29 PJ. This amount of existing generation capacity could be shut down.

Assuming that the 29 PJ of capacity shut down represents a cross-section of the existing 4,852 PJ of electrical generation capacity, it represents 6 PJ of fossil fired capacity responsible for approximately 0.5 million tonnes of carbon dioxide emissions annually.

#### Replacement of Existing Fossil Fueled Generation

As shown in Exhibit 3.7 the IFSD model forecast additions to non-fossil generation capacity of 1,666 PJ between 1988 and 2005.

The existing fossil fuel generation capacity is 966 PJ. After adjusting for the portion that could be shut down due to reductions in demand, the fossil fueled capacity is 960 PJ. In short, the forecast nuclear and hydro capacity additions are more than enough to displace all existing fossil capacity.

Replacing existing fossil fueled generating stations with new non-fossil fueled generation reduces the carbon dioxide emissions due to electricity generation to zero. Hence the carbon dioxide emissions reduction achieved by this process is the existing emissions (85 million tonnes/yr) less the savings due to the demand reductions (0.5 million tonnes/yr) or 84.5 million tonnes per year.

Social Cost of Replacing Existing Fossil Fueled Generation

The social cost of replacing existing fossil fueled generation with new non-fossil generation is the cost of advancing the replacement dates of those stations. The real cost of electricity generated using new non-fossil generation will be approximately the same as that generated by existing fossil fueled stations. Hence, the net cost is the cost of replacing the existing stations before the end of their useful lives.

To estimate this cost it is assumed that half the useful life of each existing fossil fueled generation station is lost and that the opportunity cost of this capacity is equal to the cost of new fossil fueled capacity, approximately $2,000 per kW. The 960 PJ of primary energy that would be replaced represents, after allowing for reserve margins and average utilization, about

15,000 MW of generation capacity.[14] The social cost of replacing this existing fossil fired capacity is estimated at $15 billion.

Replacing all existing fossil fueled generation with non-fossil generation would avoid the need for installation of systems to reduce sulphur oxides and nitrogen oxides emissions. These measures are currently planned. The total cost of those controls is likely to be several billion dollars. Avoiding the costs of $SO_x$ and $NO_x$ abatement measures reduces the $15 billion dollar cost for carbon dioxide abatement. However, in the absence of data on aggregate $SO_x$ and $NO_x$ abatement costs, the estimate of $15 billion for carbon dioxide abatement will be used.

Substitution of Electricity for Fossil Fuels

Further reductions in carbon dioxide emissions can be achieved by substituting non-fossil generated electricity for fossil fuels in the end use sectors. For example, the balance of the forecast growth in non-fossil generation capacity (1666 - 960 = 706 PJ) represents a secondary demand of approximately 215 PJ. Assuming that this electricity is generated and displaces an equivalent amount of fossil fuel in the residential, commercial or industrial sectors, the reduction in carbon dioxide emissions would be between 10 and 20 million tonnes annually depending upon the specific fuel displaced.

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14 The installed thermal generation capacity in Canada is just over 31,000 MW. In principle all existing thermal capacity would be replaced. The discrepancy between the installed capacity of 31,000 MW and the replacement capacity is at least partly explained by the inclusion of mothballed plants, remote generation, peaking capacity and lower demand. Without a detailed analysis it is impossible to say whether these factors explain the entire difference. However, the $15 billion replacement cost is conservative because it is not reduced by the savings on $SO_x$ and $NO_x$ controls.

This is a costly option because it requires construction of additional generation capacity to displace fossil fuels. It is not analysed further because the measures already identified are sufficient to meet the abatement target.

### 3.5.4 Electricity Generation Measures

An extensive list of technologies that have the potential to reduce carbon dioxide emissions associated with the generation of electricity is presented in Appendix E. The list includes:

- more efficient fossil fueled generation technologies such as fluidized bed and combined cycle technologies;
- non-fossil generation technologies such as wind, photovoltaic, tidal, ocean, geothermal, fuel cells, etc;
- more efficient transmission technologies;
- energy storage technologies; and
- carbon dioxide removal technologies.

A number of these technologies are expected to be commercially available and economically competitive, at least in some applications, by 2005.

As is clear from the analysis presented above, these technologies are not critical abatement strategy at the national level by 2005. Some regions, as will be seen below, can be expected to encounter difficulties reaching a proportionate share of the carbon dioxide abatement target because of their mix of electrical generation. The technologies noted above will offer those provinces more options.

After 2005 further reductions in carbon dioxide emissions will increasingly come from substitution of non-fossil electricity for fossil fuels. Many of the electricity generation technologies identified will play a greater role as that process becomes more important.

### 3.6 Summary of Carbon Dioxide Reduction Potential

The estimates of carbon dioxide reduction potential are summarized in Exhibit 3.8. The technical potential exceeds the Toronto Climate Conference reduction target regardless of the specific value chosen for that target. The measures economically attractive to society achieve 65 to 75 percent of the carbon dioxide emissions reduction target. The market penetration may already be reflected in the energy demand forecast. Even if the market penetration scenario is not implicit in the energy forecast, it achieves less than 15 percent of the recommended target for carbon dioxide emissions.

The finding that energy conservation measures offer the greatest potential for reduction of carbon dioxide emissions over the period to 2005 is consistent with U.S. findings.[15] Exhibit 3.8 shows that energy conservation measures, including conservation of electricity, account for 75 to 80 percent of the total carbon

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15 J.A. Edmonds, W.B. Ashton, H.C. Cheng and M. Steinberg, "A Preliminary Analysis of U.S. $CO_2$ Emissions Reduction Potential from Energy Conservation and the Substitution of Natural Gas for Coal in the Period to 2010", U.S. Department of Energy, February 1989. The study concludes that larger contributions to $CO_2$ emissions reduction appear to be available through energy conservation than through substitution of natural gas for coal. Our results indicate that conservation measures (including conservation of electricity) accounts for roughly 75% of the total $CO_2$ emissions reduction. The relative magnitudes of the reductions due to conservation and substitution are consistent with the above study.

**EXHIBIT 3.8: OVERALL SUMMARY $CO_2$ EMISSIONS**

(Millions of Tonnes Annually By 2005)

| | Market Penetration | Measures Economically Attractive to Society | Technical Potential |
|---|---|---|---|
| Savings due to energy efficiency measures | 31 | 103 | 177 |
| Savings due to demand-side management measures | 20 | 76 | 88 |
| Savings due to replacement of existing and future fossil-fired electricity generation with non-fossil generation | - | 42 | 85 |
| Total Reduction | 51 | 221 | 350 |
| Toronto Climate Conference Reduction Target | 291-342 | 291-342 | 291-342 |

dioxide emissions reduction. The balance of the emissions reduction is achieved through substitution for fossil fuels primarily in the generation of electricity. The relative magnitudes of these sources of carbon dioxide emissions reductions are also consistent with American findings.

The conclusion is clear. The Toronto Climate Conference target can be achieved, but only by doing virtually everything that is technically feasible. On the other hand most measures that need to be implemented to achieve the target are economically attractive from the perspective of Canadian society. Although most measures are economically attractive from society's perspective they can be expected to be difficult to implement in the market place. This is reflected in the relatively small reduction achieved under the market penetration scenario.

### 3.7 Costs of Reduced Carbon Dioxide Emissions

Most of the measures selected as being cost-effective means of reducing carbon dioxide emissions improve the efficiency of energy use. In many of these cases, the value of the energy saved over the life of the measure exceeds the initial investment required. As a result, the net cost of the measure is negative. In other words, most of the measures selected reduce carbon dioxide emissions, save energy and save money.

The total "cost" associated with the carbon dioxide emission reduction measures in each penetration scenario is as follows:

Total Cost Savings Resulting
from Implementation of Carbon
Dioxide Abatement Measures
(billions of 1988 $)

| Market Penetration | Measures Economically Attractive to Society | Technical Potential |
|---|---|---|
| -$42 | -$150 | -$99 |

Implementing the measures economically attractive to society yields a net benefit of $150 billion dollars on the basis of energy savings alone. No monetary value has been assigned to the carbon dioxide emissions reduction. The economic benefit to society under the technical potential scenario is smaller; $99 billion. This is because measures with a net cost to society are assumed to be implemented to achieve a larger reduction in carbon dioxide emissions. In effect the cost of the additional carbon dioxide reductions is $395 per tonne of reduced annual emissions.[16] It is important to note however, that the technical potential scenario still yields a significant economic benefit to society.

The economic benefits associated with lower carbon dioxide emissions can not be achieved without significant investment. The measures are analysed in terms of the incremental capital cost needed to capture the reduced carbon dioxide emissions; the incremental cost of a more energy efficient automobile assuming that a new automobile is to be purchased in any case. The incremental capital investments needed to reduce carbon dioxide

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16 Cost of $150 - $99 = $51 billion yield emissions reductions of 350-221 = 129 million tonnes per year.

emissions and reap the associated economic benefits are estimated as follows:

| Market Penetration | Measures Economically Attractive to Society | Technical Potential |
|---|---|---|
| | (billions of 1988 dollars) | |
| $23 | $74 | $128 |

### 3.8 Reduced Emissions of Other Gases

The reduced emissions of other greenhouse gases due to implementation of the specified carbon dioxide abatement measures are shown in Exhibit 3.9.

The reductions in the volumes of other gases are smaller than those of carbon dioxide. This simply reflects the proportions of the various gases emitted by combustion of fossil fuels. Carbon monoxide emissions are dominated by the transportation sector, which is responsible for about 80 percent of those emissions.

The carbon dioxide equivalence reflects the combined carbon dioxide and methane emissions reductions. Emissions factors for nitrous oxide are not available and the other gases are not, strictly speaking, greenhouse gases. Although the methane emissions are small, it is 55 times as potent as carbon dioxide on a unit weight basis. Adding the combustion related emissions of methane to the emissions of carbon dioxide raises the overall impact by less than 0.01 percent.

The electrical generation sector is the dominant source of reductions of nitrogen oxides emissions, accounting for roughly 70 percent of the total. The other major contributor to nitrogen

EXHIBIT 3.9: REDUCED EMISSIONS OF OTHER GASES DUE TO IMPLEMENTATION OF CARBON DIOXIDE ABATEMENT MEASURES

(Thousands of Tonnes Per Year)

| | $CO_2$ | CO | $CH_4$ | $CO_2$ Equivalence | $NO_x$ |
|---|---|---|---|---|---|
| Technical Potential | | | | | |
| Residential | 19,581 | 3 | 1 | 19,638 | 16 |
| Multi-residential | 6,080 | 1 | * | 6,086 | 5 |
| Commercial | 24,546 | 5 | * | 24,573 | 21 |
| Industrial | 87,152 | 9 | 1 | 39,762 | 57 |
| Transportation | 39,702 | 173 | * | 87,152 | 198 |
| Electricity Generation | 173,696 | 32 | 1 | 173,765 | 618 |
| Total | 350,757 | 223 | 4 | 350,976 | 915 |
| Measures Economically Attractive to Society | | | | | |
| Residential | 10,301 | 2 | 1 | 10,301 | 8 |
| Multi-residential | 4,382 | 1 | * | 4,382 | 4 |
| Commercial | 11,656 | 2 | * | 11,668 | 10 |
| Industrial | 9,323 | 2 | * | 9,339 | 17 |
| Transportation | 67,833 | 127 | * | 67,833 | 139 |
| Electricity Generation | 118,264 | 22 | * | 118,284 | 422 |
| Total | 221,759 | 156 | 2 | 221,807 | 600 |
| Market Penetration | | | | | |
| Residential | 3,433 | 1 | * | 3,433 | 3 |
| Multi-residential | 1,519 | * | * | 1,519 | 1 |
| Commercial | 4,194 | 1 | * | 4,199 | 4 |
| Industrial | 4,493 | 1 | * | 4,500 | 7 |
| Transportation | 17,771 | 30 | * | 17,771 | 40 |
| Electricity Generation | - | - | - | - | - |
| Total | 31,410 | 33 | * | 31,422 | 55 |

Notes: * = less than 500 tonnes per year.

oxides reduction is the transportation sector which is the source of about 20 percent of the $NO_x$ emissions reduction.

### 3.9 Effect on Tropospheric Ozone

Tropospheric ozone is a greenhouse gas. It is synthesized in the troposphere through photochemical reactions involving nitrogen oxide ($NO_x$), water vapour and gaseous hydrocarbons. There is a consensus that $NO_x$ plays a pivotal role in the formation of ozone in the troposphere.

A relationship between $NO_x$ emissions and tropospheric ozone formation is developed in Appendix D. A two part reduction in total $NO_x$ emissions to the troposphere is estimated to result in a one to two part reduction in tropospheric ozone concentrations. Based upon that relationship, the estimated changes in $NO_x$ emissions on tropospheric ozone concentrations are estimated in Exhibit 3.10. The tropospheric ozone concentrations rise from the current 20 to 100 parts per billion/volume to 27 to 134 parts per billion/volume under the market penetration scenario.

Tropospheric ozone concentrations fall slightly to 19 to 94 parts per billion/volume with the measures economically attractive to society. The technical potential scenario reduces tropospheric ozone concentrations to 14 to 68 parts per billion/volume.

### 3.10 Regional Impacts

The overwhelming majority of the measures that would need to be implemented are economically attractive from a social perspective. And implementing all of the measures included as part of the technical potential still yields a net economic benefit to society. Thus there should be net economic benefits to all regions as a result of implementing the carbon dioxide abatement measures.

EXHIBIT 3.10: IMPACT OF CARBON DIOXIDE ABATEMENT MEASURES ON TROPOSPHERIC OZONE CONCENTRATION

| | Market Penetration | Measures Economically Attractive To Society | Technical Potential |
|---|---|---|---|
| $NO_x$ emissions due to fossil fuel combustion, 1988 (000 tonnes) | 853 | 853 | 853 |
| $NO_x$ emissions due to fossil fuel combustion, 2005 (000 tonnes) | 1,377 | 1,377 | 1,377 |
| $NO_x$ emissions reduction due to carbon dioxide emissions abatement measures (000 tonnes) | 55 | 178 | 297 |
| $NO_x$ emissions reduction due to substitution of non-fossil generation for fossil fueled electrical generation (000 tonnes) | Nil | 422 | 618 |
| Revised $NO_x$ emissions due to fossil fuel combustion 2005 (000 tonnes) | 1,322 | 777 | 462 |
| Change in $NO_x$ emissions from 1988 | + 55% | - 9% | - 46% |
| Change in ozone formation | + 34% | - 6% | - 33% |
| Tropospheric ozone concentrations in 2005 (parts per billion/volume) | 27-134 | 19-94 | 14-68 |

Notes: Assumes that the change in $NO_x$ emissions occurs on a global basis

### 3.10.1 Distribution of Impacts of Measures Aimed at the End Use Sectors

The residential, commercial and transportation sectors are distributed roughly according to population. For that reason the economic benefits of implementing the carbon dioxide abatement measures can be expected to be distributed roughly in accordance with population.

That will not be strictly true because commercial floor space and transportation activity may not have precisely the same distribution as the population. In addition the condition of the building stock and climatic conditions vary across the country.

Single detached houses on the prairies have the highest space heating loads because of climatic conditions and the lowest economic retrofit potential.[17] Single detached homes in the Atlantic region have the highest economic retrofit potential. Variations of this sort are likely to exist in the multi-residential and commercial sectors as well. They give rise to small differences between the distribution of population and the distribution of benefits by region.

Canadian industry is concentrated in southern Ontario and Quebec. The measures specified for the industrial sector are economically attractive from a social perspective. Implementation of those measures should therefore be beneficial. Tracing the distribution of benefits quickly runs into complexities well beyond the scope of this analysis.

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17 Energy, Mines and Resources Canada, Updated Analysis of Thermal Retrofit in the Canadian Residential Sector, James F. Hickling Management Consultants Ltd., March 1988.

Depending upon the industry structure, the benefits that result from implementation of the carbon dioxide abatement measures take the form of lower prices to consumers or higher profits for the firms. Lower prices benefit the consumers, who are generally more widely distributed than the areas where industry is concentrated. Higher profits may lead to higher wages or greater returns to shareholders. To the extent that benefits lead to higher wages they will be concentrated where the industries are located. Higher returns to shareholders are likely to be more widely distributed because direct and indirect (via mutual funds, insurance policies, etc) share ownership is dispersed across the country.

Measures that reduce the demand for electricity are economically attractive and capable of implementation in all parts of the country. The benefits should be proportionally higher in areas where electricity prices are higher.

### 3.10.2 Impacts of Measures Aimed at Electricity Generation

An analysis of the regional impacts of carbon dioxide emissions reduction on electrical generation is shown in Exhibit 3.11. The analysis is based on the technical potential case and uses a national emissions reduction target of 291 million tonnes.

Each region has a carbon dioxide emissions reduction target based on reaching 80 percent of its 1988 emissions by 2005. Direct reductions in carbon dioxide emissions equivalent to the national average are assumed to be achieved in each region. In other words, each regional reduces fossil fuel use in the residential and commercial sectors by 45 percent, in the industrial sector by 24 percent and in the transportation sector by 49 percent by 2005. The carbon dioxide emissions reduction estimated for each region reflects the projected mix of fossil fuels used by each sector in that region in 2005.

**EXHIBIT 3.11: REGIONAL ANALYSIS OF IMPACTS OF CARBON DIOXIDE EMISSIONS REDUCTION STRATEGY ON ELECTRICAL GENERATION**

| | ATLANTIC | QUEBEC | ONTARIO | MANITOBA | SASKATCHEWAN | ALBERTA | B.C., YUKON & N.W.T. | CANADA |
|---|---|---|---|---|---|---|---|---|
| Estimated $CO_2$ emissions 2005 (millions tonnes) | 66 | 88 | 225 | 17 | 40 | 112 | 80 | 627 |
| Estimated $CO_2$ emissions 1988 (milions tonnes) | 45 | 63 | 145 | 12 | 25 | 80 | 49 | 419 |
| Toronto Climate Conference target 2005 (million tonnes) | 36 | 50 | 116 | 9 | 20 | 64 | 40 | 335 |
| $CO_2$ emissions reduction target 2005 (million tonnes) | 29 | 37 | 108 | 7 | 20 | 48 | 41 | 291 |
| Direct reduction of $CO_2$ emissions 2005 (million tonnes) | 16 | 35 | 65 | 7 | 9 | 23 | 22 | 177 |
| Reduction in $CO_2$ emissions needed from electrical generation to meet target | 13 | 3 | 43 | * | 11 | 24 | 19 | 114 |
| Forecast $CO_2$ emissions due to electrical generation 2005 (million tonnes) | 24 | 1 | 55 | * | 19 | 56 | 19 | 174 |
| "Allowable" $CO_2$ emissions due to electrical generation 2005 (million tonnes) | 11 | (2) | 11 | * | 7 | 32 | * | 60 |
| $CO_2$ emissions due to electrical generation 1988 (million tonnes) | 14 | * | 24 | * | 10 | 37 | 1 | 85 |
| Forecast secondary demand for electricity 2005 (PJ) | 163.7 | 799.4 | 766.4 | 71.9 | 61.7 | 176.0 | 243.4 | 2,282.5 |

**EXHIBIT 3.11: REGIONAL ANALYSIS OF IMPACTS OF CARBON DIOXIDE EMISSIONS REDUCTION STRATEGY ON ELECTRICAL GENERATION (Continued)**

| | ATLANTIC | QUEBEC | ONTARIO | MANITOBA | SASKATCHEWAN | ALBERTA | B.C., YUKON & N.W.T. | CANADA |
|---|---|---|---|---|---|---|---|---|
| Reduction in secondary demand due to demand-side management measures (PJ) | 59.9 | 271.1 | 272.8 | 28.0 | 24.0 | 62.0 | 84.9 | 802.6 |
| Revised secondary demand for electricity in 2005 (PJ) | 103.9 | 528.3 | 493.6 | 43.9 | 37.7 | 114.1 | 158.5 | 1,479.9 |
| Primary demand for electricity in 2005 (PJ) | 355.1 | 1,700.3 | 1,560.0 | 155.6 | 140.8 | 420.0 | 488.5 | 4,823.3 |
| Forecast non-fossil generation capacity 2005 (PJ) | 310.2 | 2,559.1 | 1,811.2 | 250.2 | 41.2 | 22.6 | 556.6 | 5,551.0 |
| Fossil fueled generation capacity needed 2005 (PJ) | 44.9 | Nil | Nil | Nil | 99.6 | 397.4 | Nil | Nil |
| Existing fossil fueled generation capacity displaced by 2005 (PJ) | 111.0 | 2.4 | 257.2 | 3.9 | 3.5 | 31.2 | 13.9 | 965.3 |
| Estimated $CO_2$ emissions due to remaining fossil fueled generation 2005 (million tonnes) | 4 | Nil | Nil | Nil | 9 | 38 | Nil | Nil |
| Excess $CO_2$ emissions due to remaining fossil fueled generation 2005 (million tonnes) | Nil | Nil | Nil | Nil | 2 | 6 | Nil | Nil |

Notes: * = less than 0.5

The direct carbon dioxide emissions reduction is subtracted from the target reduction to get the amount by which emissions due to electrical generation must be reduced if the target is to be met. The estimated carbon dioxide emissions due to the generation of electricity in each region in 2005 are reduced by this figure. That leaves the "allowable" carbon dioxide emissions for the electrical generation sector in each region.

Quebec has negative allowable emissions. In other words, Quebec could not meet the carbon dioxide emissions reduction target in the manner outlined. It would need to achieve higher rates of direct carbon dioxide emissions reductions in the end use sectors probably by substituting non-fossil electricity for fossil fuels. Manitoba and British Columbia are just able to meet their targets.

This analysis is based on a national reduction target of 291 million tonnes per year. If a target of 342 million tonnes per year were used, Manitoba, British Columbia and Ontario would all be in the same situation as Quebec.

The carbon dioxide emissions due to electrical generation are estimated after taking account of the potential for:

- reducing the demand for electricity; and
- substituting non-fossil generation for fossil fueled generation.

First the forecast secondary demand for electricity in 2005 is reduced by the estimated potential for demand-side management. The forecast demand for electricity in 2005 is reduced by 46 percent in the residential and commercial sectors and by 25 percent in the industrial sector in each region. The added load for real electrification is allocated to Ontario (83%) and

Quebec (17%). The revised secondary demand for electricity in 2005 is below the 1988 figure in every region except Ontario.

The revised secondary demand is adjusted for transmission losses using factors specific to each region. The demand for electricity is then expressed as a primary demand, again on a regional basis.

The primary demand for electricity is compared to the IFSD model forecast of non-fossil generation capacity available by 2005. In all regions, except the Atlantic, Saskatchewan and Alberta, the forecast non-fossil capacity is more than sufficient to meet the total revised demand for electricity. As a result all existing fossil fired generation capacity could be displaced except in Alberta, Saskatchewan and the Atlantic. Even in those three regions significant reductions in existing fossil fueled generation are possible.

Finally, the carbon dioxide emissions from the required fossil fueled generation capacity are estimated and compared to the "allowable" emissions for the Atlantic, Saskatchewan and Alberta. The "allowable" emissions are exceeded by Saskatchewan and Alberta.

Both provinces could meet their target by using combined cycle coal and/or natural gas for generation of electricity. They could also examine sources of non-fossil generation other than those covered by the IFSD model. Or they could purchase non-fossil electricity from neighbouring provinces. Saskatchewan and Alberta may also have opportunities to reduce carbon dioxide emissions in the production of fossil fuels, or their use as feedstocks which were beyond the scope of this study.

## 3.11 Beyond 2005

The measures identified as being capable of implementation by 2005 involve significant improvements in energy efficiency and a considerable expansion of hydroelectric generation capacity. What can be done after 2005 to achieve further reductions in carbon dioxide emissions?

Further improvements in energy efficiency should be possible but the gains are likely to be substantially smaller than those projected for the period to 2005. The smaller gains result from the fact that the measures proposed involve efficient new stocks of energy-using equipment and extensive retrofits of existing stocks of energy-using facilities and equipment. Hence, even with continuing improvements in the energy efficiency of new facilities and equipment the potential for retrofit after 2005 will be limited and the net gains upon replacement of existing stock after 2005 will be smaller.

After 2005 the carbon dioxide abatement strategy will need to shift somewhat. Non-fossil electricity will need to be substituted for fossil fuels in the end use sectors to offset the declining contribution of improved energy efficiency. The most likely candidates appear to be hydroelectric and nuclear as proven large generation sources and (in no particular order) solar, nuclear, wind, fuel cells, biomass on a sustainable production basis, and possibly nuclear fusion.

The hydroelectric potential anticipated to be developed by 2005 does not exhaust that resource. Canada is estimated to have about 50,000 MW of hydroelectric capacity considered likely to be suitable for future development. Much of this potential has a low head (less than 40 m) and most of the rest is at relatively remote sites. Substantial additional potential has been

identified as being technically feasible, but with economic or environmental difficulties.[18]

Realistically, hydroelectric power is unlikely to be able to make a much larger contribution to carbon dioxide emissions abatement after 2005 than the roughly 20 percent share of overall reductions it could contribute before 2005.

Nuclear power is far less constrained by geographic considerations. Public concerns over the safety of nuclear generating stations and the permanent disposal of radioative wastes have greatly curtailed the construction of new nuclear generating stations. The only new nuclear generating station anticipated by the analysis is Ontario Hydro's Darlington station which is expected to begin operation in the early 1990's.

Research, development and demonstration of non-fossil generation technologies is needed over the next 15 years to enhance the prospect of their becoming commercially available in the future.

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18 Electric Power in Canada 1987, Energy, Mines and Resources Canada, pp 83, 84.

# 4.0 REDUCTION OF CFC AND FUGITIVE METHANE EMISSIONS

## 4.1 Chlorofluorocarbons and Climate Warming

Chlorofluorocarbons (CFCs) contribute to climate warming in two ways:

- CFCs destroy stratospheric ozone which inhibits climate warming; and
- CFCs contribute directly to climate warming.

These effects are discussed below.

### 4.1.1 Ozone Depletion

Stratospheric ozone is a thin layer of gas 15 to 35 kilometers above the surface that protects the Earth from ultraviolet radiation. In 1972 NASA undertook to study the effect of chlorine compounds emitted by space shuttles on stratospheric ozone. That study found that large amounts were being released into the atmosphere through the use of such products as foams, refrigerants, air conditioners, and aerosols. It demonstrated that one chlorofluorocarbon (CFC) molecule had the potential to destroy thousands of ozone molecules.

In the past decade, a shift has been recorded in the vertical distribution of ozone. The amount of ozone is decreasing in the stratosphere, but increasing in the troposphere. A thinner stratospheric ozone layer allows more ultraviolet radiation to reach the Earth's surface. This warms the surface and increases the amount of heat that must be radiated back into space. Tropospheric ozone inhibits the radiation of heat into space. This causes climate warming, the greenhouse effect.

### 4.1.2 Chlorofluorocarbons and the Greenhouse Effect

Apart from their ozone depletion effects chlorofluorocarbons and other halogenated gases are radiatively active (greenhouse) gases. They absorb and radiate back to the Earth's surface infrared radiation that would otherwise escape into space. Molecule for molecule, the effect of CFCs on climate warming is about 10,000 times more powerful than that of carbon dioxide.

## 4.2 Chlorofluorocarbons and their Properties

Chlorofluorocarbons and halons are useful in a wide variety of industrial processes because they are versatile, non-toxic, non-flammable and have low thermal conductivity.[19] They replaced more environmentally hazardous industrial chemicals that were carcinogenic and/or flammable, such as ammonia in refrigerants.

Unfortunately, the stability that makes halogenated gases attractive to industry is one reason why they are now no longer acceptable for our environment. They are so non-reactive that they degrade only when they reach the stratosphere and are exposed to ultraviolet radiation.

### 4.2.1 Properties of Different Halogenated Gases

Several different types of CFCs and halons are currently used in industrial applications. They include:

| | |
|---|---|
| CFC-11 | $CCl_3F$ |
| CFC-12 | $CCl_2F_2$ |
| CFC-113 | $C_2Cl_3F_3$ |
| CFC-114 | $C_2Cl_3F_4$ |

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[19] Halons differ from CFCs in that they contain bromine as well as chlorine atoms in their molecular structure.

| | |
|---|---|
| CFC-115 | $C_2Cl_3F_5$ |
| Halon 1301 | $CBrF_3$ |
| Halon 1211 | $CF_2ClBr$ |

These chemicals are distinct in that they contain different numbers of chlorine, fluorine and bromine atoms. The properties of the principal CFCs and halons are summarized in Exhibit 4.1. The most widely used CFCs are CFC-12, CFC-11 and CFC-113 in that order. The rate of growth of CFCs and halons in the atmosphere is generally over 5 percent per year and for some gases is as high as 20 percent per year.

The life of CFCs and halons in the atmosphere is quite long, being over 100 years in most cases. Halon 1211 at 25 years has the shortest life span, while CFC-115 has the longest life span at 380 years. The impact of a given gas is measured in terms of its ozone depletion potential and its greenhouse effect (radiative activity). Ozone depletion potential and greenhouse effect are both measured relative to CFC-12, the most common of the gases. Halons have a much larger ozone depletion potential than CFCs. The ozone depletion potential of other gases and the greenhouse effects generally vary by $\pm$ 40 percent from those of CFC-12. In general, the more chlorine and fluorine and the fewer carbon atoms a CFC contains, the longer it will last in the atmosphere and the higher will be its ozone depleting potential.

### 4.2.2 "Soft" Chlorofluorocarbons

Other CFCs, sometimes called "soft" CFCs, have much lower ozone depleting potentials because they contain hydrogen in their molecular structure and/or do not contain chlorine or bromine. CFCs containing hydrogen (such as HCFC-22 or HCFC-142b) will react with hydroxyl radicals found in the lower atmosphere, thereby degrading more quickly. CFCs which contain only fluorine

**EXHIBIT 4.1: SUMMARY OF THE MAIN CFC-CHARACTERISTICS INFLUENCING THE OZONE LAYER AND THE CLIMATE**

| Compound | Potential Use | Estimated Canadian Production in 1985[1] (000 tonnes) | Lifetime (yrs.) | Growth in Troposphere (%/yr.) | Greenhouse Effect Relative To CFC-12 | Ozone Depletion Potential Relative To CFC-11 | Share of the Total Contribution to Ozone Depletion (%) |
|---|---|---|---|---|---|---|---|
| CFC-11 ($CFCl_3$) | Foam, aerosol, refrigerators and air conditioners | 4.9 | 65 | 4-5 | 0.4 | 1.0 | 25.8 |
| CFC-12 ($CF_2Cl_2$) | Refrigerators and air conditioners, aerosol, foam | 8.7 | 130 | 5-6 | 1.0 | 1.0 | 44.7 |
| CFC-113 ($C_2F_3Cl_3$) | Solvent, refrigerant | 4.1 | 90 | 12-15 | 0.3-0.8 | 0.8 | 11.7 |
| CFC-114 ($C_2F_4Cl_2$) | Foam, refrigerant | n/a | 180 | 6 | | 0.6 | |
| CFC-115 ($C_2F_5Cl$) | Mixed with CFC-22 to form CFC-502 used as refrigerant | 0[2] | 380 | | 1.2 | 0.6 | |
| Halon 1301 ($CBrF_3$) | Fire extinguishant (permanent) | 0.42 | 110 | | 0.8 | 10.0 | 3.7 |
| Halon 1211 ($CF_2BrCl$) | Fire extinguishant (portable) | 0.22 | 25 (12-15) | 20 | | 3.0 | 0.9 |

1 Estimates of Canadian CFC production was calculated by adjusting the estimated global production in 1985 to reflect U.S. use patterns in 1985. These are similar to Canadian production patterns. Canadian CFC production figures were based on 2.5% of the weighted global production figures.

2 CFC-115 is not produced in Canada.

(such as HCFC-134a or HCFC-152a) do not pose a threat to the ozone in the stratosphere.

Although these soft CFCs have greatly reduced ozone-depletion potentials and degrade more quickly in the atmosphere, they remain greenhouse gases. Nonetheless, soft CFCs are considered to be important substitutes to fully halogenated CFCs because they can act as "bridging" chemicals until technologies are developed which do not require such chemicals.

### 4.3 Use of Chlorofluorocarbons

The principal uses of CFCs in Canada are summarized in Exhibit 4.2. The largest uses of CFCs are refrigeration and air conditioning and manufacture of foams. Together those applications account for over three-quarters of the total consumption of CFCs.

Not all of the CFCs used are released into the atmosphere immediately. Emission rates vary depending on the CFC use. Aerosol emissions occur almost immediately, while most other uses emit CFCs more slowly. For instance, rigid foams retain CFCs within the cell structure and only release them when the product is crushed. Similarly, CFCs used in air conditioners and refrigerators are not emitted until the cooling system is damaged or the appliance is destroyed. The same is true of halons in fire extinguishers. These stores of CFCs are often referred to as "banks".

The nature of many of the uses to which CFCs and halons are put makes it difficult to estimate emissions as distinct from use. However, the long life of these chemicals in the atmosphere means that virtually all CFCs and halons ever produced are still present in "banks" or in the atmosphere.

EXHIBIT 4.2: SUMMARY OF CFC USAGE IN CANADA

| Process Group | CFC s Used | Total Estimated Usage (Kilotonnes) | CFC Usage Overall (Percent) |
|---|---|---|---|
| Refrigeration and Air Conditioning | -11, -12, -113, -114, -115* | 7.5 | 36.1% |
| Rigid Foams | -11, -12, -113, -114 | 6.9 | 33.2% |
| Flexible Foams | -11 | 1.7 | 8.2% |
| Aerosol Products | -11, -12, -113, -114 | 1.9 | 9.1% |
| Solvents | -113 | 2.0 | 9.6% |
| Other Applications (Includes Sterilants) | -12, -113 | 0.8 | 3.8% |
| Total | | 20.8 | 100.0% |

Source: Commercial Analysis of Chlorofluorocarbon Applications in Canada, Project Report Prepared For Chemical Control Department, Environment Canada, 1988.

Efforts to control CFC emissions have been directed primarily at reducing the use, and ultimately emissions, of these compounds. A second area of interest is reducing the "bank" of halons and CFCs, although that often requires that a suitable substitute be found first.

Fortunately, substitutes or alternatives are available, or are expected to become available, over the next 5 to 8 years for most uses of CFCs and halons. Those substitutes, together with the lead time and the likely reduction of CFC use that can be achieved are summarized in Exhibit 4.3. Overall it is estimated that use of CFCs and halons can be reduced by 85 percent from current levels by 2000.

## 4.4 Efforts to Reduce Use of CFCs

### 4.4.1 The Montreal Protocol

The Montreal Protocol is an international agreement to limit emissions of specified substances that deplete the ozone layer. It was negotiated over a period of several years in a process co-ordinated by the United Nations Environment Program. The Protocol has been signed by forty-six nations. Fifteen of these countries, including Canada, have ratified it. At present the Protocol controls chlorofluorocarbons and halons. Specifically, the Protocol restricts the consumption and therefore emissions of:

CFC-11
CFC-12
CFC-113
CFC-114
CFC-115
Halon 1211
Halon 1301

**EXHIBIT 4.3: REDUCTION POTENTIAL OF CHLOROFLOUROCARBONS BY PROCESS GROUP**

| Process Group | Use | Substitution | CFCs Replaced | Availability | Reduction |
|---|---|---|---|---|---|
| Rigid Foams | | | | | |
| . Polyurethane | Blowing Agent | CFC-11/Water | CFC-11 | Limited | Low |
| | | HCFC-123 | CFC-11 | 3 Years | 100 Percent |
| | | HCFC-141b | CFC-11 | 3 Years | 100 Percent |
| | Recovery | Carbon Bed Adsorption | CFC-11 | Now | 5 Percent |
| | Insulation | Product Substitutes i.e., Fiberglass | CFC-11 | Now | > 50 Percent |
| . Polystyrene | Blowing Agent | HCFC-22 | CFC-12 | Now | 100 Percent |
| | | HFC-134a | CFC-12 | > 1 Year | 100 Percent |
| | | HCFC-142b | CFC-12 | > 1 Year | 100 Percent |
| | Operating Loss Reduction | Vacuum Chambers | CFC-12 | Now | 10 Percent |
| | | Carbon Bed Adsorption | CFC-12 | Now | 10 Percent |
| | Insulation | Product Substitutes | CFC-12 | Now | > 50 Percent |
| . Phenolic Foam | Blowing Agent | HCFC-123 | CFC-11 | 7 - 8 Years | > 50 Percent |
| | | HCFC-141b | CFC-11 | 7 - 8 Years | > 50 Percent |
| | | HCFC-22 | CFC-12 | 7 - 8 Years | > 50 Percent |
| | Manufacturing | Increased Operating Efficiency | CFC-11 | Not Feasible | Low |
| | | | CFC-12 | Not Feasible | Low |
| | Insulation | Product Substitutes | CFC-11 | Now | > 50 Percent |
| | | | CFC-12 | Now | > 50 Percent |

EXHIBIT 4.3: REDUCTION POTENTIAL OF CHLOROFLOUROCARBONS BY PROCESS GROUP (Continued)

| Process Group | Use | Substitution | CFCs Replaced | Availability | Reduction |
|---|---|---|---|---|---|
| Flexible Foams | Blowing Agent | Methylene Chloride | CFC-11 | Now | Limited |
| | | Carbon Monoxide (FIB Process) | CFC-11 | 10 Years | 40 Percent |
| | | CFC-11/Water | CFC-11 | Now | 75 Percent |
| | | HCFC-123 | CFC-11 | 8-10 Years | 100 Percent |
| | | HCFC-141b | CFC-11 | 8-10 Years | 100 Percent |
| | Substitutes Agent | Natural and Synthetic Fiberfill | CFC-11 | Now | 75 Percent |
| | | Latex Foams | CFC-11 | Limited | > 1 Percent |
| | | Engineered Plastic Cushion | CFC-11 | Not Known | Not Known |
| | Chemical Modifications | Modified Polyol Systems | CFC-11 | 5-10 Years | 50 Percent |
| | | Ultracel | CFC-11 | Now | High |
| | Process Technology | Carbon Adsorption | CFC-11 | Now | Limited |
| | | Vertical Foam Chambers | CFC-11 | Now | 25 Percent |

**EXHIBIT 4.3: REDUCTION POTENTIAL OF CHLOROFLOUROCARBONS BY PROCESS GROUP (Continued)**

| Process Group | Use | Substitution | CFCs Replaced | Availability | Reduction |
|---|---|---|---|---|---|
| Refrigeration and Air Conditioning | Solvents for Flushing Systems | Aqueous Based Cleaning Solutions | CFC-11, -12, and 113 | Immediately | 100 Percent |
| | Leak Detection Gas | Helium Based Leak Testing | CFC-12 | In Use Now | < 1 Percent |
| | | HCFC-22 | | | < 1 Percent |
| | | Nitrogen | | | < 1 Percent |
| | 14-Ounce Cans CFC-12 | Elimination, Use Bigger Cans | CFC-12 | Immediately | |
| | Refrigerant in New Equipment | HFC-134a | CFC-12 | 3-8 Years | 100 Percent |
| | | HCFC-22 | | Now | 100 Percent |
| | | HCFC-152a | | Not Known | |
| | | CFC-502 | | Now | 100 Percent |
| | Servicing in Equipment | Isolation Valving | CFC-11 | Now | Small |
| | | Storage Vessels | CFC-12 | Now | Small |
| | New Design | Isolation Valving | CFC-11 | Now | 1-10 Percent |
| | | Storage Vessels | CFC-12 | Now | 1-10 Percent |
| | Refrigerant in Mobile A/C | HFC-134a | CFC-12 | 3 Years | 25 Percent |
| | | HCFC-22 | | Now | 25 Percent |
| | Refrigerant | HFC-123 | CFC-11 | 5-10 Years | 100 Percent |
| | | HCFC-22 | | Now | 100 Percent |
| | Chiller Systems | High Pressure Centrifugal Chillers | CFC-11 | | 100 Percent |

EXHIBIT 4.3: REDUCTION POTENTIAL OF CHLOROFLOUROCARBONS BY PROCESS GROUP (Continued)

| Process Group | Use | Substitution | CFCs Replaced | Availability | Reduction |
|---|---|---|---|---|---|
| Solvents | Cleaning Agents | Terpene | CFC-113 | Now | Medium |
| | | Acetone | CFC-113 | Now | Medium |
| | | Water | CFC-113 | Now | Medium |
| | | Alcohol | CFC-113 | Now | Medium |
| | | Methyl Chloride | CFC-113 | Now | Low |
| | | Trichloroethylene | CFC-113 | Now | Low |
| | Production Technology | Low Solid Fluxes That Do Not Require Cleaning | CFC-113 | Now | Low-Medium |
| | Recovery/ Conservation | Enclosing Equipment to Reduce Evaporation | CFC-113 | Now | 50-100 Percent |
| | | Reducing Use of Spray Systems | CFC-113 | Now | 50-100 Percent |
| | | Recycling of Used Solvents | CFC-113 | Now | 50-100 Percent |
| Sterilants | Cleaners | EO/CO2 | CFC-12 | Now | 100 Percent |
| | | HFC-134a | CFC-12 | > 5 Years | 100 Percent |
| | | EO + Nitrogen | CFC-12 | Limited | Low |
| | Reclamation | Acid-Water Scrubbing | CFC-12 | > 5 Years | Low |
| | Alternate Products | Disposable Instruments | CFC-12 | Now | Low |

**EXHIBIT 4.3: REDUCTION POTENTIAL OF CHLOROFLOUROCARBONS BY PROCESS GROUP (Continued)**

| Process Group | Use | Substitution | CFCs Replaced | Availability | Reduction |
|---|---|---|---|---|---|
| Aerosols | Propellant | Hydrocarbon | CFC-11 | Now | 100 Percent |
| | | | CFC-12 | Now | 100 Percent |
| | | HCFC-22 | CFC-11 | Now | 100 Percent |
| | | | CFC-12 | Now | 100 Percent |
| | | CO2 | CFC-12 | Now | 100 Percent |
| | | HCFC-123 | CFC-11 | 4 Years | > 75 Percent |
| | | HFC-134a | CFC-12 | 4 Years | > 75 Percent |
| Fire Extinguishants | Permanent | Dry Chemical Extinguishing Systems Halon 1211 | Halon 1301 | 5-10 Years | High |
| | Portable | Dry Chemical Extinguishing Systems | Halon 1211 | 5-10 Years | Small<br>Limited |

Mechanical mixtures of the above CFCs are also restricted.

The schedule for reductions is:

- Reduce consumption of designated CFCs in 1990 to actual consumption in 1986;
- Reduce CFC consumption in 1994 to 80 percent of 1986 levels;
- Reduce CFC consumption in 1999 to 50 percent of 1986 levels; and
- Freeze consumption of halons at 1986 levels in 1992.

Environment Canada, responsible for implementing the Protocol in Canada, will soon be introducing regulations under the new Canadian Environmental Protection Act to meet these requirements.

### 4.4.2 National Objectives

Since the Montreal Protocol was drafted, the consensus of scientific opinion is that 1986 emissions of CFCs and halons must be reduced by at least 85 percent to stop further growth in concentrations of CFCs and halons in the atmosphere.

In recognition of this new consensus, Environment Canada announced its intention to further reduce emissions. This includes banning non-essential uses of CFCs and halons and introducing additional control measures such as recycling, recapturing and reuse codes of practice. On February 21, 1989, the Minister of the Environment announced that there would be an 85 percent reduction in emissions of ozone depleting substances in Canada by 1999.

The remaining fifteen percent will be eliminated by law as soon as safe substitutes are available.

### 4.4.3 Provincial Objectives: Ontario and British Columbia

In February, 1989, Ontario became the first province to ban products that destroy the ozone layer. The Environmental Protection Act will be amended to eliminate the manufacture and use of CFCs and halons. About half of all CFCs and halons produced in Canada (about 10 kilotonnes) are used in Ontario.

The ban is to be introduced in stages. The first step is elimination of all CFCs used in aerosols (except prescription drugs) and in packaging by July 1, 1989. Dates for further emissions will be set later.

Since Ontario's announcement, the province of British Columbia has announced its intention to introduce a similar ban on ozone depleting substances.

### 4.4.4 Industry's Response

Industry has said that it is willing to develop and adopt technologies that reduce the emissions of CFCs and halons. Its concerns over implementing such technologies can be summarized in three points:

- Government regulatory action must be co-ordinated between international, national and provincial objectives to ensure commonality and competitiveness across markets.

- The costs of converting to alternate products and processes must be distributed evenly across the industry and such conversions must be implemented according to a reasonable time frame.

- Government must take a concerted pro-active role in CFC and halon emission reduction to achieve these first two objectives.

In short, it appears that governments in Canada are committed to significantly reducing use of CFCs and halons. Industry appears willing and able to implement the necessary measures, provided that the regulations are implemented equitably.

## 4.5 Capture of Fugitive Methane Emissions

Fugitive methane emissions from four sources are examined:

- open pit and underground coal mine operations;
- the petroleum industry;
- land fill sites; and
- biogas sources (wastewater systems and animal waste).

Methane emissions from each of these sources are estimated and a judgement is made as to the fraction of those emissions that are economically recoverable.

## 4.6 Coal Mining

### 4.6.1 Methane in Coal

Gas is contained in coal deposits in two forms:

- free gas in the fissures and pores of the coal and in other rock; and
- gas adsorbed on the internal surface of the coal.

The free gas in fissures and pores represents a small fraction, usually 5 to 10 percent, of the total gas content of coal.

The greater part of the gas contained in in situ coal is held at the surface of the coal pores in an adsorbed form. The quantity of gas adsorbed by the coal is very high since the internal surface area of coal is very large (of the order of 90 square metres per gram).

Adsorption is a reversible physical phenomenon. The reverse phenomenon of adsorption is called desorption. The desorbable gas is the quantity given off when the coal passes from seam pressure to atmospheric pressure.

The gas content of coal depends primarily upon its rank and depth. Usually a low rank coal has a lower gas content than a higher ranked coal. A coal seam lying close to the surface is under less pressure than a deeper deposit. As well the overburden covering a shallow deposit allows more methane to escape.

Typically, gas from coal is 90 to 98 percent methane. The gas content of coal in Canada ranges between 4 and 21 cubic metres per tonne.

### 4.6.2 Fugitive Methane Generated by Coal Mining

In 1988 Canada produced about 70 million tonnes of coal: 66.6 million tonnes from open pit mines and 3.5 million tonnes from underground mines. This mining activity generated approximately 500 million cubic metres of fugitive methane.

### 4.6.3 Fugitive Methane in an Underground Mine

Methane has presented problems in coal mines for centuries. Methane is released when the confining pressure is reduced by mining. The fugitive methane accumulates in the mine where it

mixes with air. Concentrations of methane in air of 4.5 to 14 percent are explosive and therefore very dangerous.

Typically fugitive methane in underground mines is controlled using extensive ventilation systems that dilute the methane and exhaust it to the atmosphere. As deeper, gassier, seams are mined conventional ventilation methods may not be able to cope with the methane emitted. In such cases methane is collected by a closed drainage system which delivers fairly concentrated methane to the surface where it is available for use.

Methane can be recovered from the ventilation system exhaust air or from a closed methane drainage system.

The ventilation system exhaust air usually contains 0.5 to 2.0 percent methane. This represents a large energy loss in the form of methane vented to the atmosphere and in the form of energy used to drive the ventilation fans for the large volumes of air. The diluted methane in the return air can be used to fuel boilers if they are located near the upcast shaft.

A methane drainage system captures methane from the coal seam in a high concentration and delivers it to the surface through a pipeline. The captured methane does not contaminate the ventilation system and provides for safer mining conditions. Usually, the concentration of collected methane is around 60 percent. The collected methane becomes fugitive methane if it is released to the atmosphere.

A methane drainage system was installed in the Lingan Mine in Cape Breton in 1985. The system handles about 90,000 cubic metres of methane per day. It cost $3.4 million to install in 1985. Annual operating costs are about $300,000 and a further $300,000 per year is needed for ongoing capital costs. The

resulting cost of the methane is less than 5 cents per cubic metre.

Since the system was completed in 1985 the methane has been vented to the atmosphere because no market has been found for the gas.

### 4.6.4 Fugitive Emissions from Open Pit Coal Mines

Collection of fugitive methane from operating open pit coal mines is not feasible.

However, before the open pit mine begins operation, collection of fugitive methane is possible. At that time the coal deposit is covered with overburden which keeps the methane in place. Using virgin coal demethanation (VCD) techniques, methane can be collected before the mine starts operation or the overburden is disturbed. The VCD technique accesses the coal using a borehole from the surface. The gas then evolves and flows up the borehole. Because of the low rate of emission of methane from coal, demethanation wells generally have a low productivity unless the coal is stimulated. Several stimulation techniques are available.

Open pit coal mines are usually situated in remote locations and an infrastructure is installed to provide the significant amounts of energy that such a mine requires. Some of this energy requirement could be offset by utilizing the fugitive methane. The cost of the methane recovered from a virgin coal deposit is likely to be well below 5 cents per cubic metre.

### 4.6.5 Marketing Fugitive Methane from Coal Mines

The quality of fugitive methane recovered from coal mines is highly variable. Before it can be used it must often be

upgraded. The processing required depends upon the market. The principal options are:

- production of pipeline quality gas with a nominal heating value of 37.6 MJ per cubic metre;
- production of industrial fuel gas with a nominal heating value of about 20 to 22 MJ per cubic metre; and
- onsite generation of electrical power for sale to utility or industrial customers.

These options have different production costs. The best option for a given location depends upon site specific factors such as proximity to gas pipelines, large industries and electric utility transmission lines. The choice will also be affected by the price of natural gas and the prices that gas and electric utilities are prepared to pay for purchases of gas and electricity.

### 4.6.6 Economically Recoverable Fugitive Methane from Coal Mines

Only about 5 per cent of Canada's coal comes from underground mines. In the short term these mines offer the best scope for recovery of fugitive methane. It can be recovered from the ventilation system return air or, in the case of the Lingan mine, from the methane drainage system. In the longer term, methane can be recovered from new open pit mines, or new parts of existing open pit mines, using virgin coal demethanation techniques.

It is judged to be both technologically and economically viable to capture 50 percent of fugitive methane from coal mining operations by 2005. The development of markets for fugitive methane will be a key determinant of the extent of methane capture.

## 4.7 Fugitive Methane in the Petroleum Industry

### 4.7.1 Methane in Natural Gas and Oil Resources

There is a significant difference between methane in coal and a conventional natural gas or oil reservoir. The methane in coal is generated from the coal and is in an adsorbed state, with desorption being a slow process. Natural gas or oil has migrated from the source rock to, and has become compressed in, the reservoir rock without any binding mechanism. As such, the potential production rate for natural gas or oil is high.

Conventional natural gas normally has a methane content of around 81 percent.

### 4.7.2 Fugitive Methane from Natural Gas and Oil Fields

There are several reasons for releasing, or flaring, methane into the atmosphere (flared gas is either burned on release or left unburned at certain lower flow rates):

- To establish the expected production from a newly drilled gas well it has to be tested. Testing procedures require the release of gas into the atmosphere at high flow rates sometimes for days or even weeks.

- Every producing oil well produces some natural gas as a by-product. If the oil well is not located close to a natural gas pipeline the gas will be flared.

- Gas processing plants provide pipeline quality gas, and separate higher hydrocarbons and sulphur from the gas. During the process methane, in a gas mixture with hydrocarbons of a lower heating value, is flared.

. The lack of a gathering system for methane in isolated areas means the methane is flared.

### 4.7.3 Reducing Fugitive Methane Emissions in the Petroleum Industry

The main goal of the natural gas industry is to produce and sell as much natural gas as economically possible. Since the main product is methane gas, the industry tries to maximize production, including minimizing or eliminating fugitive methane.

The Alberta Energy Resources Conservation Board is very sensitive about waste gas. It requires that every effort be made to minimize the volume of the fugitive methane. Before permission is granted to operate an oil or gas well all circumstances must be scrutinized to avoid wasting methane unnecessarily. However, the Board also takes into consideration the existing low price of the methane.

### 4.7.4 Fugitive Methane Emissions by the Petroleum Industry

An estimated 2.7 billion cubic metres of natural gas with a methane concentration of 72 percent (2.0 billion cubic metres of methane) was flared in Canada in 1987. This methane, which represents about 1.6 percent of total gas production, technically might not be considered "fugitive" in the sense that most of it is burned (which produces carbon dioxide) rather than released as methane. An estimated 10 percent of this methane (0.2 billion cubic metres) could be captured economically.

## 4.8 Fugitive Methane from Land Fill Sites

### 4.8.1 Methane from Land Fills

Methane gas is generated during the decomposition of organic waste in sanitary land fill sites. Until the early 1970's, this gas was considered a nuisance at best and a potential hazard at worst.

Raw land fill gas typically consists of 50 to 60 percent methane and 40 to 50 percent carbon dioxide. The heating value is about 18.7 MJ per cubic metre. The concentration of methane in land fill gas depends upon the composition of organic matter in the refuse decomposing at that time and the extent of any non-methanogenic activity occurring in the land fill.

Actual total gas production and gas production rates from decomposing solid wastes are difficult to obtain. Land fill measurements of total gas generation rates are in the range of 6 to 38 cubic metres per year per tonne of wet refuse during the period of maximum methane formation.

### 4.8.2 Emissions from Canadian Land Fill Sites

Data on methane emissions from Canadian land fill sites are not available. Crude estimates put the annual emissions at 1,650 million cubic metres of methane. This estimate is subject to a margin of error of 50 percent. That quantity of methane represents almost one percent of Canada's annual secondary energy demand.

Speculative data for the United States transposed to Canada suggest that roughly half of the fugitive methane from land fills could be economically recoverable. Almost one-quarter of all municipal solid waste disposal sites in the United States have

methane recovery or mitigation systems. They are necessary to comply with the Resource Conservation and Recovery Act. Fewer than ten percent of those sites recover the methane for energy use.

### 4.8.3 Use of Land Fill Gas

Land fill gas can be used to generate heat for water heating space heating, or similar uses. Or it can be used as a fuel for electrical generation. A dual fuel system should also be given consideration.

To recover the gas, wells must be drilled into the land fill. The wells have a relatively low flow rate, so a fairly high density of wells is required. Although the wells are not deep, the relatively large number of wells and the associated collection system entail a large capital cost. That in turn means that recovery of land fill methane is most attractive for larger sites.

## 4.9 Additional Biogas Sources of Fugitive Methane

### 4.9.1 Fugitive Methane from Wastewater Systems

The biological process of anaerobic digestion has been used by conventional municipal wastewater treatment facilities for almost 100 years. During anaerobic digestion, metabolic by-products such as methane, carbon dioxide and hydrogen sulphide gases are produced. The methane gas could be captured at this stage.

The City of Calgary's Bonneybook Sewage Plant generates about 30,000 cubic metres of methane per day from a wastewater flow of about 400 million litres. About 80 percent of this is utilized to generate electricity for peak shaving from the electrical grid (about 20 to 30 percent of needs). It is not economical to

generate more electricity as the cost per kWh exceeds the base price of the electrical grid. A similar system operates in Edmonton.

No data are available on the quantity of fugitive methane that can be captured from sewage treatment plants.

### 4.9.2 Fugitive Methane From Animal Manures

Anaerobic digestion of animal manures has been demonstrated to be an effective resource management tool. The system does not need to be high-tech to be effective. A medium calorific value gas is generated and can be used by the animal husbandry facility as heating fuel or for electrical generation.

Significant amounts of fugitive methane can easily be collected from animal manure. An American study found that 28.7 billion cubic metres of biogas could be produced from manures in the United States. If 15 percent is taken as an estimate of the Canadian potential, it amounts to 4,300 million cubic metres of biogas.

## 4.10 Summary of Fugitive Methane Emissions

The estimated annual emissions of fugitive methane and the fraction of those emissions judged to be economically recoverable is as follows:

| Source | Estimated Annual Emissions of Methane (millions of $m^3$) | Fraction Estimated to be Economically Recoverable | Potential Reduction of Fugitive Emissions (million of $m^3$) | Potential Reduction of Fugitive Emissions (1,000 tonnes) |
|---|---|---|---|---|
| coal mines | 500 | .5 | 250 | 180 |
| petroleum industry | 2,000 | .1 | 200 | 140 |
| land fills | 1,650 | .5 | 800 | 570 |

In addition methane could be recovered from anaerobic digestion of municipal wastewater and animal manures.

# 5.0 CONCLUSIONS

The conclusions must be interpreted in the context of the study. The study provides a broad, national overview of measures that can be implemented to reduce atmospheric greenhouse gas emissions due to:

- combustion of fossil fuels;
- use of CFCs and halons; and
- capture fugitive methane emissions.

A great deal of work remains to confirm or modify estimates, verify the feasibility of measures across the country, etc. The conclusions must therefore be treated as broad, national conclusions which may not apply in their entirely to specific regions of the country.

## 5.1 Reduction of Emissions due to Fossil Fuel Combustion

A "significant reduction" of projected 2005 emissions of carbon dioxide due to fossil fuel combustion is achievable but very ambitious. A "significant reduction" in this context means the Toronto Climate Conference recommendation of a 20 percent reduction from 1988 emissions of carbon dioxide by 2005.

A "significant reduction" of projected carbon dioxide emissions by 2005 is very ambitious because it requires that all appropriate abatement measures be vigorously implemented.

Basically, there are no choices. The only option is to do everything that will reduce carbon dioxide emissions. Moreover, it is necessary to do everything effectively to achieve a significant reduction in projected emissions.

The reductions in emissions that can be achieved from a single sector or by displacing a single fuel fall far short of the desired results. Effective measures must be implemented in all sectors.

Most measures to reduce carbon dioxide emissions are economically attractive from a societal perspective. Implementing the selected measures to reduce projected carbon dioxide emissions will yield both economic and environmental benefits to Canada.

The energy conservation measures are generally economically attractive from society's perspective on the basis of energy savings alone with the energy prices forecast for the mid-1990s. Ascribing an economic value to the environmental benefits associated with these measures would simply make them more attractive.

Most (about 75%) of the reduction of projected carbon dioxide emissions is achieved through implementation of energy conservation measures. These measures do not entail a deterioration in the quality of energy service, such as space conditioning comfort levels. They are measures that permit equal or better service to be provided with the use of less energy.

The remainder of the reduction of projected carbon dioxide emissions is achieved through the non-fossil generation of electricity. The types and amounts of non-fossil generation needed over the period to 2005 are feasible. And they are cost competitive with fossil-fired generation.

Achieving a "significant reduction" in projected carbon dioxide emissions is more manageable and less costly if implementation starts soon. A "crash program" to reduce carbon dioxide emissions starting in 2000 is neither environmentally nor economically sound. Many components of the stock of energy using

facilities and equipment, such as buildings, heating and cooling systems, and industrial equipment, have a long life. Energy efficiency is easier and less costly to improve in new facilities and equipment. The sooner the process of improving the new stock begins, the lower the cost of achieving the desired improvements.

Significant regional differences are found in the ability to meet the Toronto Climate Conference target. It appears that Quebec, Saskatchewan and Alberta would experience the greatest difficulties meeting their carbon dioxide reduction targets. More detailed regional analyses are needed to confirm this finding.

The most effective strategy for the period to 2005 and possibly slightly beyond is to implement energy conservation measures. If the desired reductions in carbon dioxide emissions are achieved, the scope for further energy efficiency improvements will be limited.

Beyond 2005 the strategy will need to shift to greater reliance on non-fossil generation of electricity to displace, fossil fuels in the end use sectors. Research and development of such technologies is needed over the next 15 years to enhance the prospect of their becoming commercially available in the future.

### 5.2 Reduced Use of CFCs and Halons

Todate most efforts directed at reducing the greenhouse effect have focussed on CFCs. An international agreement, the Montreal Protocol, to reduce their use has been adopted by 46 countries.

Recent government policy announcements indicate a target of an 85 reduction in the use of CFCs and halons before 2000 with eventual elimination of these chemicals. That target appears to be technically and economically achievable. Industry has

indicated that it is prepared to cooperate in the achievement of those targets. Its main concern is fair and reasonable regulation governing the reduced use of CFCs and halons.

The main area yet to be addressed is the recovery and destruction of "banked" CFCs and halons before they are released to the environment.

### 5.3 Capture of Fugitive Methane Emissions

Fugitive methane emissions can be economically captured from:

- petroleum and natural gas production;
- coal mines;
- land fills;
- municipal wastewater treatment; and
- animal manures.

Fugitive emissions in the petroleum industry are already carefully scrutinized. Due to the size of the industry, the emissions are still significant. But the potential for economic recovery is low.

Fugitive methane emissions can be recovered from underground coal mines. And it can be recovered from open pit coal mines before they are developed. A significant reduction in emissions could be achieved economically. Current efforts to reduce methane emissions from coal mines are negligible.

Land fills are the largest of the fugitive methane emission sources considered. Recovery and use can be economic for large land fills. Little recovery is currently practiced.

Anaerobic digestion of municipal wastewater and animal manures produces methane that can be economically recovered. Data on the

potential for these applications are not available. Some western Canadian wastewater treatment plants capture methane and use it to generate electricity.

The principal need in all cases is for regulations or incentives to encourage collection and use of the methane and to create markets for the gas and/or electricity produced.

# APPENDIX A

## Approach to Analysis of the Potential For Reduction of Combustion-Related Emissions

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# 1.0 INTRODUCTION

This appendix provides an overview of the methodology used to analyse measures with the potential to reduce emissions of carbon dioxide from fossil fuel combustion. Detailed data on the carbon dioxide abatement measures are provided in Appendix E.

# 2.0 OVERVIEW

The approach used for the analysis is summarized in Exhibit A.1. An extensive list of measures that have the potential to reduce emissions of carbon dioxide is compiled. Each of these measures is documented in terms of its:

- energy performance;
- cost characteristics;
- potential number of installations;
- reduction of greenhouse gas emissions;
- cost-effectiveness in terms of emission reductions; and
- potential for emissions abatement.

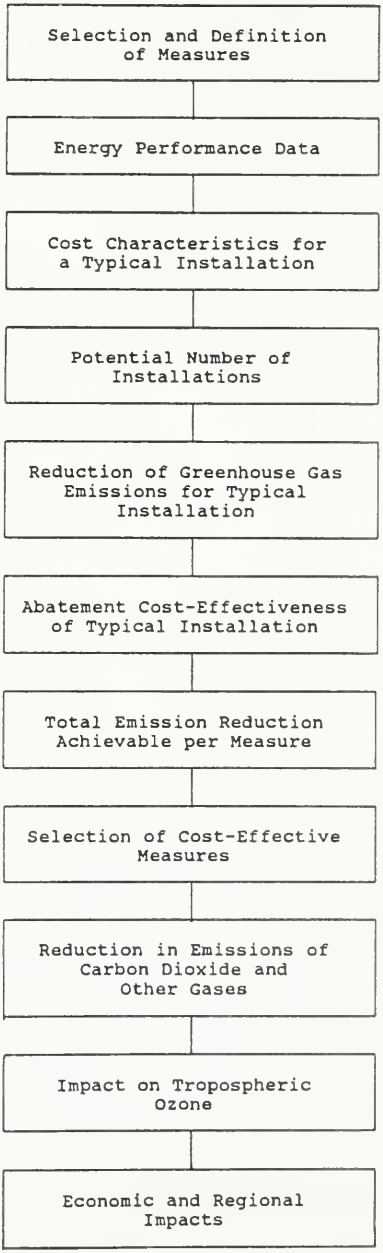
The most cost-effective carbon dioxide abatement measures are selected. The impacts of these measures are estimated in terms of:

- reduced emissions of carbon dioxide;
- reduced emissions of other greenhouse gases; and
- total cost of the measures.

The regional impacts of the selected measures are analysed and the impacts on tropospheric ozone formation are assessed.

These steps in the analysis are discussed briefly in the following sections.

EXHIBIT A.1: ANALYTICAL APPROACH $CO_2$ EMISSIONS REDUCTION


Selection and Definition of Measures
Energy Performance Data
Cost Characteristics for a Typical Installation
Potential Number of Installations
Reduction of Greenhouse Gas Emissions for Typical Installation
Abatement Cost-Effectiveness of Typical Installation
Total Emission Reduction Achievable per Measure
Selection of Cost-Effective Measures
Reduction in Emissions of Carbon Dioxide and Other Gases
Impact on Tropospheric Ozone
Economic and Regional Impacts

# 3.0 IDENTIFICATION OF CARBON DIOXIDE ABATEMENT MEASURES

## 3.1 Categories of Measures

Measures with the potential to reduce emissions of greenhouse gases due to combustion of fossil fuels were identified from the available literature. The potential measures were classified into the following categories; measures that:

- conserve energy and so reduce fossil fuel use;
- substitute a less carbonaceous fuel for a more carbonaceous fuel;
- substitute a non-carbon energy source for a carbonaceous fuel;
- remove greenhouse gases from combustion emissions; and
- recycle greenhouse gases.

## 3.2 A Typical Installation

Each measure is defined in terms of a "typical" installation such as a house, an automobile, a square metre of commercial floor space, or an industry sector, for which performance and financial data are available.

A measure typically involves a specific end use or application and fuel. For example, a building envelope retrofit for homes heated with natural gas. As the example indicates a certain amount of aggregation is needed; a building envelope retrofit may include a variety of specific measures such as ceiling, wall and basement insulation, caulking and weather tightening, storm windows, etc. The "building envelope retrofit" measure used in the analysis reflects a typical mix of these specific measures.

The change in emissions due to a building envelope retrofit depends upon the fuel used for space heating. Thus, it is

necessary to define three "building envelope retrofit" measures; one each for natural gas, light fuel oil and electricity. The need to define measures in terms of the existing fuel increases the number of measures that must be included in the analysis.

### 3.3 Organization of Abatement Measures

The number of measures identified is so numerous that they are organized into six sectors, as follows:

- residential;
- multi-residential;
- commercial and institutional;
- industrial (general and specific industries);
- transportation; and
- electricity generation.

# 4.0 DATA RELATING TO CARBON DIOXIDE ABATEMENT MEASURES

## 4.1 Introduction

The data needed with respect to each measure to complete the analysis fall into several categories as follows:

- energy performance;
- cost characteristics;
- potential number of installations;
- reduction of greenhouse gas emissions per installation;
- cost-effectiveness in terms of emissions reductions; and
- potential for emissions abatement.

Each category of information is discussed below. The detailed data relating to individual measures together with sources and notes are presented in Appendix E.

## 4.2 Energy Performance Data

The energy performance data for a measure provide the energy use and fuel type before and after the measure has been installed, together with the percent savings. Specifically, the energy performance data relating to each measure include:

- fuel type before the measure is implemented (See Exhibit A.2 list of energy types).

- annual energy use by a typical unit before the measure is implemented. It is the amount of input energy for electricity generating measures.

- fuel type after the measure is implemented (see Exhibit A.2). In the case of energy conservation measures the energy type is the same before and after the measure has

EXHIBIT A.2: LIST OF ENERGY TYPES

ANTHRACITE
IMPORTED BITUMINOUS
CANADIAN BITUMINOUS
SUB-BITUMINOUS
LIGNITE
COKE
STEAM
PROPANE
LIQUID PETROLEUM GASES (LPG's)
MOTOR GASOLINE
DIESEL FUEL
AVIATION GASOLINE
AVIATION TURBO
LIGHT FUEL OIL
HEAVY FUEL OIL
NATURAL GAS
COMPRESSED NATURAL GAS (CNG)
ELECTRICITY
METHANOL
ETHANOL
HYDROGEN
WOOD

been implemented. For substitution measures the fuel type after implementation of the measure is the substitute fuel.

- projected annual energy use by a typical unit after the measure is implemented.

- by-product energy. This is useful (i.e., could be sold) electricity, steam or heat produced as a by-product by the measure. In the case of co-generation and electricity generation measures, it is the electricity produced.[1]

- percent energy savings. The energy use of a typical unit before installation of the measure and after installation of the measure are converted to energy units using the conversion factors in Exhibit A.3. The percent energy savings due to implementation of the measure is then calculated.

The energy saving is compared to estimates of projected savings reported in the literature. The percent energy savings is not specifically used in the analysis. Rather it is used as a "reasonableness check" on the energy performance data, since the literature most often reports the potential impact of these measures in terms of their impact on energy use.

The data relate to measures that can be in normal use by 2005 in typical facilities of the time. This is interpreted as the projected performance of new units during the 1995-2000 period. As a result, the energy use should reflect anticipated performance of new units during the 1995-2000 period, unless the

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[1] In principle this also includes by-product heat and steam from electricity generation. Despite concerted efforts, sales of by-product steam and heat from generating stations have been negligible. For this reason the by-product heat and steam have not been included in the analysis.

EXHIBIT A.3: ENERGY - NATURAL UNIT CONVERSION FACTORS

| FUEL TYPE | NATURAL UNIT | CONVERSION FACTOR (TJ per unit) |
|---|---|---|
| COAL | | |
| - ANTHRACITE | kilotonnes | 27.70 |
| - IMPORTED BITUMINOUS | " | 29.00 |
| - CANADIAN BITUMINOUS | " | 27.60 |
| - SUB-BITUMINOUS | " | 18.80 |
| - LIGNITE | " | 14.40 |
| COKE | " | 28.83 |
| PETROLEUM COKE | megalitres | 42.38 |
| COKE OVEN GAS | gigalitres | 18.61 |
| PROPANE | megalitres | 25.53 |
| BUTANE | " | 28.62 |
| ETHANE | " | 18.36 |
| LPG's | " | 26.56 |
| MOTOR GASOLINE | " | 34.66 |
| DIESEL FUEL | " | 38.68 |
| KEROSENE | " | 37.68 |
| CRUDE OIL | " | 38.51 |
| LIGHT FUEL OIL | " | 38.68 |
| HEAVY FUEL OIL | " | 41.73 |
| AVIATION TURBO FUEL | " | 35.93 |
| NATURAL GAS | gigalitres | 27.23 |
| ELECTRICITY | gigawatt hours | 3.60 |

Sources: Statistics Canada. "Quarterly Report on Energy Supply-Demand in Canada" 57-003 July, 1988 and Energy, Mines and Resources Canada, Interfuel Substitution and Demand Model.

technology is changing very rapidly or the equipment stock changes quickly.

## 4.3 Cost Characteristics for a Typical Installation

The cost data for each measure cover its capital and operating costs. All costs are expressed in 1988 Canadian dollars.

### 4.3.1 Capital Cost of a Typical Installation

The capital costs are estimated as the cost of installing a typical unit in the 1995-2000 period, unless dramatic cost changes are anticipated after that time. Capital costs include monitoring equipment, building renovations and any other ancillary investments needed for a typical installation.

The capital costs are the incremental capital costs; the initial cost net of any investments that would otherwise be required. For example, consider the installation of a high efficiency natural gas furnace to replace an oil furnace when the latter needs replacement. The capital cost is equal to the cost of the new gas furnace plus the cost of a gas connection and modifications to the heating system (if any) less the cost of a new oil furnace.

The analysis assumes that replacement measures, such as the furnace example, are implemented on the normal replacement cycle. Advancing the replacement cycle by installing the high efficiency gas furnace before the oil furnace needs replacement is not specifically addressed by the analysis. Advancing the replacement cycle reduces the emissions sooner, but at higher cost. The timing of emissions reductions over the period to 2005 is not critical to this study.

4.3.2 Annual Operating Cost Exclusive of Fuel

Annual operating costs other than fuel are estimated for the system in place before the measure is implemented and for the system in place after the measure has been implemented.

In the case of the furnace replacement discussed in the previous section, the annual maintenance cost of an oil furnace would be the cost included in this category. The annual operating costs other than fuel after the furnace has been replaced is the annual maintenance cost of a high efficiency gas furnace.

4.3.3 Annual Energy Cost

Annual energy costs are calculated before and after the measure has been implemented. The amount is calculated by applying the forecast 1995 energy price (expressed in 1988 dollars) for the appropriate fuel to the annual energy use as reported under the energy performance data.

A table of forecast energy prices for 1995 is provided in Exhibit A.4.

The energy price forecast for 1995 is taken from the IFSD Model 15-24 forecast.[2] For the purposes of the economic evaluation of carbon dioxide abatement measures energy prices are assumed to be constant in real terms. Since the forecast assumes that real energy prices will rise, the use of a constant energy price makes

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2 For a description of the forecast see "Long-Term Energy Outlook 1987-2005", Energy Market Analysis Division, Energy, Mines and Resources Canada, June 1988. The forecast used in this study is based on the assumption that Texas crude oil prices rise from U.S. $15 per barrel in 1988 to U.S. $24 per barrel in 2005 (both in 1986 U.S. dollars).

EXHIBIT A.4: ENERGY PRICES

| Fuel - Sector | Price per Physical Unit 1995 Dollars | | Price per Gigajoule 1995 Dollars $/GJ | Price per Gigajoule 1988 Dollars $/GJ |
|---|---|---|---|---|
| SUB-BIT. COAL - ELECTRICITY | 2.19 | $/GJ | 2.19 | 1.63 |
| BIT. COAL - COMMERCIAL | 85.43 | $/TONNE | 2.36 | 1.76 |
| BIT. COAL - ELECTRICITY | 2.19 | $/GJ | 2.19 | 1.63 |
| BIT. COAL - INDUSTRIAL | 105.48 | $/TONNE | 2.91 | 2.17 |
| BIT. COAL - RESIDENTIAL | 116.87 | $/TONNE | 3.23 | 2.40 |
| DIESEL - TRANSPORTATION | 45.20 | C/L | 11.69 | 8.70 |
| GASOLINE - TRANSPORTATION | 43.40 | C/L | 12.52 | 9.32 |
| TURBO FUEL - TRANSPORTATION | 30.90 | C/L | 8.60 | 6.40 |
| METHANOL - TRANSPORTATION | 43.40 | C/L | 16.34 | 12.16 |
| PROPANE - TRANSPORTATION | 43.40 | C/L | 17.00 | 12.66 |
| HFO - COMMERCIAL | 21.30 | C/L | 5.10 | 3.80 |
| HFO - ELECTRICITY | 5.02 | $/GJ | 5.02 | 3.73 |
| HFO - INDUSTRIAL | 21.00 | C/L | 5.03 | 3.75 |
| LFO - COMMERCIAL | 42.40 | C/L | 10.96 | 8.16 |
| LFO - INDUSTRIAL | 41.30 | C/L | 10.68 | 7.95 |
| LFO - RESIDENTIAL | 42.80 | C/L | 11.07 | 8.24 |
| NATURAL GAS - COMMERCIAL | 6.32 | $/GJ | 6.32 | 4.70 |
| NATURAL GAS - ELECTRICITY | 5.40 | $/GJ | 5.40 | 4.02 |
| NATURAL GAS - INDUSTRIAL | 5.54 | $/GJ | 5.54 | 4.12 |
| NATURAL GAS - RESIDENTIAL | 7.41 | $/GJ | 7.41 | 5.52 |
| CNG - TRANSPORTATION | 24.76 | | 0.00 | 7.14 |
| ELECTRICITY - COMMERCIAL | 7.11 | C/KWH | 19.75 | 14.70 |
| ELECTRICITY - INDUSTRIAL | 4.18 | C/KWH | 11.61 | 8.64 |
| ELECTRICITY - RESIDENTIAL | 5.67 | C/KWH | 15.75 | 11.72 |
| ELECTRICITY - TRANSPORTATION | 7.11 | C/KWH | 11.62 | 8.65 |

C/L - Cents/Litre

the measures appear somewhat less attractive than would otherwise be the case.

To use forecast energy prices over the life of each measure it would be necessary to assume a pattern of implementation for the measure and to have a forecast of energy prices well beyond 2005. The extended forecast of energy prices is not available. And the effort needed to use forecast energy prices in the analysis is not justified when weighed against the bias introduced by using constant (real) energy prices.

The prices of transportation fuels have been adjusted to exclude federal and provincial taxes. This allows the alternative fuels to be compared on the proper economic basis. Taxes on transportation fuels and incentives to encourage adoption of alternatives fuels are policy matters. They are avoided by using fuel costs net of federal and provincial taxes.

4.3.4 Measures Life

The anticipated life of the proposed measure expressed in years.

4.3.5 Summary Cost Data

The cost data are summarized in three ways. These summaries are:

- net measure cost;
- simple payback period; and
- levelized cost.

The three indicators of economic attractiveness convey essentially the same information. All appear in the literature and so all are calculated as part of the analysis.

Each of these calculations is described below.

4.3.6 Net Measure Cost

Conceptually net measure cost is defined as the net cost of achieving a reduction in carbon dioxide emissions by implementing a given measure.

The appropriate cost calculation must include the initial capital cost of the measure and any changes in operating costs attributable to the measure accumulated over its lifetime. A future payment is less valuable than an equivalent payment today. The difference is due to the time value of money; the fact that money could be earning interest in the interim. To adjust for the time value of money the future costs associated with a measure must be discounted to the present before they are aggregated. The cost calculated in this manner is the net present cost of the measure.

An appropriate discount rate (or interest rate) must be selected in order to calculate the net measure cost. The carbon dioxide abatement measures are evaluated from the perspective of Canadian society. When using this perspective, it is appropriate to use what economists call a "social discount rate". There is an extensive literature on the appropriate value for the social discount rate. In most cases the real (net of inflation) social discount rate is found to be between 5 and 10 percent per year. A real social discount rate of 7 percent is used in the analysis.

The cost items available for each measure are the initial capital cost, annual energy costs before and after installation, annual non-energy costs before and after installation and, where relevant, by-product energy revenues. Many of the measures analysed reduce energy use and so yield a reduction in annual energy costs. The present value of the annual saving in energy costs over the life of the measure can exceed its initial cost.

In other words the net measure cost may be negative, a net benefit.

Although the measures are being analysed in terms of their ability to effect a reduction in carbon dioxide emissions, no value is assigned to the emission reduction. The costs considered capture all of the costs relevant to each measure. Assigning a value of the reduced carbon dioxide emissions would simply make the net measure cost of each measure smaller. It would have the same effect, per kilogram of carbon dioxide, on all measures. And it creates the problem of determining an appropriate value for a one kilogram reduction in carbon dioxide emissions. It is simpler not to place a value on the carbon dioxide emissions abatement and to recognize that the "true" economic costs are understated.

The calculation of net measure cost proceeds as follows. First, the annual cost saving attributed to the measures are calculated as:

+ annual operating costs (ex energy) before implementation
+ annual energy cost before implementation
- annual operating costs (ex energy) after implementation
- annual energy cost after implementation
+ annual by-product energy revenue after implementation

Next, the present value of these annual cost savings is computed over the life of the measure using the social discount rate. Finally, the present value of the annual cost savings is subtracted from the capital cost to get the net measure cost.

The net measure cost can be positive (a net cost) or negative (a net benefit). A negative net measure cost indicates that the measure yields economic benefits in addition to the reduction in atmospheric greenhouse gas emissions achieved.

4.3.7 Simple Payback Period

To give another perspective on the economic attractiveness of the measure, its simple payback period is calculated. The simple payback period is calculated for measures whose annual cost savings (as defined above) are positive. The simple payback period is the net capital cost divided by the annual cost saving. The result is a payback period in years.

The shorter the period (i.e., smaller the number) the more attractive the measure. A measure that yields a net economic benefit with a real discount rate of 7 percent will generally have a payback period of less than ten years.

Obviously, the payback period for a measure should be less than the life of the measure. Otherwise the measure is still being paid for after it has gone out of service.

Past experience with energy conservation programs suggests that many consumers and commercial enterprises will only implement measures with a simple payback period of less than three years. Indeed, in some cases a payback period of less than one year, which implies a real discount rate in excess of 100 percent, is needed to induce consumers and businesses to implement energy conservation measures. Using this yardstick, simple payback can be used as a crude indicator of the likely market penetration of the measure.

4.3.8 Levelized Cost

Levelized cost is a third indicator of the economic attractiveness of a measure. The levelized cost is calculated as follows:

+ capital cost of the measure
+ present value of the incremental change in annual operating costs (ex energy) after implementation of the measure
+ present value of annual energy cost after implementation of the measure.

The present value in each case is calculated over the life of the measure using the real social discount rate of 7 percent. The sum is the total cost incurred after having implemented the measure. It is divided by the energy savings due to the energy conservation or fuel substitution measure.

The levelized cost is the cost per unit of energy saved or substituted by the measure. If it is lower than the cost of the energy that would otherwise be purchased, the measure is economically attractive.

## 4.4 Potential Number of Installations

The energy performance data and cost characteristics relate to a typical unit. The next step in the analysis is to estimate how many of those typical units could be installed by 2005.

Three estimates of the number of typical units that could be installed by 2005 are prepared. They are the:

. technical potential;
. measures economically attractive to society (MEAS); and
. market penetration.

### 4.4.1 Technical Potential

The technical potential is the total number of installations that are technically possible in Canada by 2005. For example, energy

efficient lighting for the commercial sector could serve all lighting needs in the sector by 2005.

To properly estimate, the technical potential requires data on the stock characteristics and care to avoid double counting. Stock characteristics must often be estimated or approximated. Comprehensive data on the amount of commercial and institutional floor space in Canada do not exist. And provincial studies devoted to determining commercial floor space have arrived at very different estimates. The approach adopted was to take energy use per unit area and divide that into the 1988 commercial sector energy demand forecast by the IFSD model. That gives internally consistent estimates of floor space and energy use.

Another example of the limitations of the stock data occurs in the residential sector. Data on the housing stock and on total energy use are available. The data do not distinguish average energy use by fuel type or age of the house. It is known that a higher proportion of older homes use oil heating and probably use more fuel because of differences in construction standards. This could have an effect on the estimated savings that could be achieved through retrofit measures. But due to lack of data, these differences are not incorporated into the analysis.

In principle, all new housing units could be heated with electricity, oil or natural gas. In practice each new home will be heated with one of those fuels. To avoid double counting the total stock of new housing units must be apportioned among the three fuels. Present, 1988, space heating fuel market shares for dwellings have been used for this purpose.

### 4.4.2 Measures Economically Attractive to Society

Measures economically attractive to society are these that yield an economic benefit to society in addition to the reduction in

greenhouse gas emissions. In the case of energy conservation measures, the measures economically attractive to society (MEAS) yield a net return to society on the basis of energy savings alone. In the case of substitution and generation measures, the MEAS have a lower net measure cost than the best alternative.

MEAS differs from the technical potential in two ways. First, a measure that is not economically attractive to society may be included in the technical potential, but it is not included in the MEAS. Second, a measure that is economically attractive to society may have a lower penetration under the MEAS then under the technical potential.

A measure that forms part of the technical potential but is not economically attractive, as determined by having a net measure cost greater than zero, has a MEAS penetration of zero.

In principle the economic potential for a measure that is economically attractive from society's perspective is the same as the technical potential. But the MEAS penetration is sometimes adjusted downward from the estimated technical potential because a measure that is economically attractive on average will not be economically attractive for all of the potential applications.

For example, energy efficient motors are attractive on average, but not in situations with very low operating periods. Hence, the economic penetration is likely to be less than the entire stock. In the case of measures for new stock, the economic potential may be reduced from the technical potential on the basis that it will be implemented only after the measure becomes commercially available rather than from 1988.

### 4.4.3 Market Penetration

Estimated market penetration by 2005 is the fraction of the technical potential likely to be achieved with no new policy measures to promote adoption.

The market penetration is generally much lower than the measures economically attractive to society. This is due to the fact that individual consumers and firms often seek much higher rates of return for energy investments than the social rate of return. In addition a variety of information and institutional barriers can inhibit the adoption of some measures. The market penetration estimates are based on the available literature and on professional judgements based on the payback period for the measure.

## 4.5 Adjustment of the Carbon Dioxide Emissions Reduction Target

The IFSD model is an econometric model. Its equations do not incorporate specific energy efficiency measures. But energy efficiency improvements have occurred in the past and these changes are probably implicit in the estimated equations used in the model. Thus the energy demand forecast probably includes some improvement in energy efficiency. But the improvement in energy efficiency is implicit and can not be determined.

Many of carbon dioxide abatement measures analysed involve energy efficiency improvements. These improvements are measured using current average performance as the base. In other words, the efficiency improvements are estimated assuming that 1988 average performance would otherwise prevail. To the extent that the IFSD energy demand forecast already incorporates some implicit energy efficiency improvements, the analysis overstates the reduction in 2005 energy demand forecast by the IFSD model that could be achieved through implementation of energy efficiency measures.

That would also overstate the carbon dioxide emissions reductions achieved by those measures.

This possible overstatement of the energy savings and carbon dioxide emission reductions relative to the IFSD forecast for 2005 can be accounted for in one of two ways. The energy savings and associated carbon dioxide emission reductions can be reduced by the amount of the overstatement. Alternatively the carbon dioxide emissions reduction target can be increased by the amount of the overstatement. While the latter approach may appear less rigorous, it is a much more convenient approach and is the one adopted for the analysis.

The problem of determining the extent to which energy savings are overstated remains. It is not possible to estimate the energy efficiency improvements implicit in the IFSD forecast without an extensive analytical effort that is well beyond the scope of this analysis. Without knowing the energy efficiency gains that are implicit in the IFSD forecast, there is no analytical way to estimate the extent of the overstatement. Faced with this situation, the Steering Committee agreed to adopt the market penetration estimate of energy efficiency improvements (both fossil fuels and electricity) as a proxy for the possible overstatement of savings due to energy efficiency measures.

The carbon dioxide emissions associated with the energy efficiency measures under the market penetration case amount to 51 million tonnes per year. This amount is added to the Toronto Climate Conference target, as estimated from the IFSD model forecast, of 291 million tonnes per year. In other words, the carbon dioxide emissions reduction target becomes 291 to 342 million tonnes per annum.

## 4.6 Reduction of Greenhouse Gas Emissions for a Typical Installation

The reduction of greenhouse gas emissions is calculated for a typical installation of each measure. For example, a carbon dioxide emission coefficient is applied to the fuel use before implementation of the measure and to the fuel use after implementation of the measure. The difference is the reduction in carbon dioxide emissions for a typical installation.

Reduction of emissions for a typical installation is calculated using emissions coefficients for carbon dioxide, carbon monoxide, methane and nitrogen oxides for various fuels. A table of emissions coefficients is presented in Exhibit A.5. Emissions coefficients are not available for nitrous oxide ($N_2O$). Reductions in emissions of $NO_x$ are calculated so that changes in tropospheric ozone can be estimated.

## 4.7 Abatement Cost-Effectiveness of a Typical Installation

The cost-effectiveness of each measure in reducing greenhouse gas emissions is calculated by dividing the net measure cost by the product of the reduction of emissions and the measure life. Although the focus is on carbon dioxide, the abatement cost-effectiveness is calculated for each gas. The abatement cost-effectiveness of the measure is expressed in terms of 1988 dollars per kilogram of $CO_2$ reduced. The same calculation is performed for each gas. The lower the cost per kilogram of greenhouse gas emissions reduced, the more attractive the measure.

## 4.8 Total Emission Reduction Achievable per Measure

The total emission reduction achievable is calculated as the product of the technical potential and the emission reduction per

EXHIBIT A.5: GREENHOUSE GAS EMISSIONS BY FUEL TYPE

| | CO2 KG/GJ | CO KG/GJ | CO | CH4 KG/GJ | CH4 | NOx KG/GJ | NOx | VOC's KG/GJ | VOC's |
|---|---|---|---|---|---|---|---|---|---|
| SUB-BIT. COAL - ELECTRICITY | 98.68 | 0.011 | 0.30 KG/MG | 0.001 | 0.02 KG/MG | 0.380 | 10.50 KG/MG | 0.001 | 0.04 KG/MG |
| BIT. COAL - COMMERCIAL | 92.06 | 0.011 | 0.30 KG/MG | 0.001 | 0.02 KG/MG | 0.380 | 10.50 KG/MG | 0.001 | 0.04 KG/MG |
| BIT. COAL - ELECTRICITY | 93.25 | 0.011 | 0.30 KG/MG | 0.001 | 0.02 KG/MG | 0.380 | 10.50 KG/MG | 0.001 | 0.04 KG/MG |
| BIT. COAL - INDUSTRIAL | 94.89 | 0.011 | 0.30 KG/MG | 0.001 | 0.02 KG/MG | 0.380 | 10.50 KG/MG | 0.001 | 0.04 KG/MG |
| BIT. COAL - RESIDENTIAL | 92.00 | 0.011 | 0.30 KG/MG | 0.001 | 0.02 KG/MG | 0.380 | 10.50 KG/MG | 0.001 | 0.04 KG/MG |
| DIESEL - TRANSPORTATION | 70.69 | 0.207 | 8.00 KG/KL | 0.000 | 0.00 KG/KL | 0.059 | 2.30 KG/KL | 0.129 | 5.00 KG/KL |
| GASOLINE - TRANSPORTATION | 67.98 | 0.141 | 4.90 KG/KL | 0.000 | 0.00 KG/KL | 0.127 | 4.40 KG/KL | 0.052 | 1.80 KG/KL |
| TURBO FUEL - TRANSPORTATION | 70.84 | 0.136 | 4.90 KG/KL | 0.000 | 0.00 KG/KL | 0.011 | 0.40 KG/KL | 0.015 | 0.53 KG/KL |
| HFO - COMMERCIAL | 80.65 | 0.014 | 0.60 KG/KL | 0.001 | 0.06 KG/KL | 0.158 | 6.60 KG/KL | 0.003 | 0.14 KG/KL |
| HFO - ELECTRICITY | 80.65 | 0.014 | 0.60 KG/KL | 0.001 | 0.03 KG/KL | 0.192 | 8.00 KG/KL | 0.002 | 0.09 KG/KL |
| HFO - INDUSTRIAL | 80.65 | 0.014 | 0.60 KG/KL | 0.003 | 0.12 KG/KL | 0.158 | 6.60 KG/KL | 0.001 | 0.03 KG/KL |
| LFO - COMMERCIAL | 73.11 | 0.016 | 0.60 KG/KL | 0.001 | 0.03 KG/KL | 0.062 | 2.40 KG/KL | 0.001 | 0.04 KG/KL |
| LFO - INDUSTRIAL | 73.11 | 0.016 | 0.60 KG/KL | 0.000 | 0.01 KG/KL | 0.062 | 2.40 KG/KL | 0.001 | 0.02 KG/KL |
| LFO - RESIDENTIAL | 73.11 | 0.016 | 0.60 KG/KL | 0.006 | 0.21 KG/KL | 0.057 | 2.20 KG/KL | 0.002 | 0.09 KG/KL |
| NATURAL GAS - COMMERCIAL | 49.46 | 0.009 | 320.00 KG/GL | 0.001 | 43.00 KG/GL | 0.043 | 1600.00 KG/GL | 0.002 | 84.00 KG/GL |
| NATURAL GAS - ELECTRICITY | 49.46 | 0.017 | 640.00 KG/GL | 0.000 | 4.80 KG/GL | 0.236 | 8800.00 KG/GL | 0.001 | 23.00 KG/GL |
| NATURAL GAS - INDUSTRIAL | 49.46 | 0.015 | 560.00 KG/GL | 0.001 | 48.00 KG/GL | 0.060 | 2240.00 KG/GL | 0.001 | 44.00 KG/GL |
| NATURAL GAS - RESIDENTIAL | 49.46 | 0.009 | 320.00 KG/GL | 0.001 | 43.00 KG/GL | 0.043 | 1600.00 KG/GL | 0.002 | 84.00 KG/GL |
| RENEWABLES - INDUSTRIAL | 97.50 | 0.000 | 2.24 KG/MG | 0.000 | 0.15 KG/MG | 0.000 | 0.084 KG/MG | 0.000 | 0.7 KG/MG |

Source: A) Alberta Department of Energy, Ian Burn (403) 427-5200, January 10, 1989, Provided by Jon Rogers, Energy, Mines and Resources.

B) Atmospheric Environment Service, data provided by Jay Barclay, Energy, Mines and Resources.

C) Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources and Volume 2: Mobile Sources, AP 42, Fourth Edition, September 1985, U.S. Environmental Protection Agency.

typical installation. The calculation is repeated with the measures economically attractive to society and the market penetration replacing of the technical potential. The result is three estimates of the emissions reductions that can be achieved, reflecting different assessments of the penetration of the measure. The calculations are performed for each gas.

In addition, a total abatement effect is calculated. Reductions in the emissions of methane are converted to equivalent carbon dioxide reductions using radiative equivalence factors. The carbon dioxide equivalents of carbon dioxide and methane are then summed to get the total abatement effect. Radiative equivalence factors are presented in Exhibit A.6.

EXHIBIT A.6: RADIATIVE EQUIVALENCE FACTORS

| Gas | Molecular Weight | Radiative Equivalence Relative to $CO_2$ Per Unit Weight |
|---|---|---|
| Carbon Dioxide | 44.01 | 1 |
| Carbon Monoxide | 28.01 | * |
| Nitrous Oxide | 44.01 | 200 |
| Methane | 16.04 | 55 |
| Ozone | 48.00 | 1,833 |
| CFC-12 | 120.91 | 3,636 |
| CFC-11 | 137.37 | 1,281 - 2,787 (ave. 2,000) |
| CFC-113 | 187.38 | 706 - 1,882 (ave. 1,300) |
| CFC-114 | 206.37 | * |
| CFC-115 | 225.37 | 2,343 |
| HCFC-22 | 86.47 | 356 |
| HCFC-1326 | 134.94 | 65 |
| HCFC-134a | 102.03 | 302 |
| Methyl Chloroform | 133.41 | 33 |
| Carbon Tetrachloride | 153.82 | * |
| Halon 1301 | 148.91 | 23,625 |
| Halon 1211 | 165.36 | * |

Notes: * No data.

Radiative Equivalence Relative to $CO_2$:

The radiative equivalence relative to $CO_2$ is calculated as follows:

$$\frac{\text{Molecular Weight } CO_2}{\text{Molecular Weight Other Greenhouse Gas}} \times \text{Index at Radiative Sensitivity (Source A)}$$

The Radiative sensitivity for CFC's, Methyl Chloroform and Halon 1301 and 1211 relative to $CO_2$ is from Source B based on CFC-12 radiative sensitivity equaling 10,000 relative to $CO_2$ in Source A.

Source A: Climate effect of one molecule relative to $CO_2$. UNEP, "Possible Effects of Man's Activities on the Ozone Layer and Climate". UNEP Policy, Support Document, London 1986. (Table provided by Paul Chenard, Energy, Mines and Resources.)

Source B: Bach, Wilfrid, "The Endangered Climate", Report No. 15, 1988, in Energy and Climate Change: What Can Western Europe Do?, F. Krause and W. Bach (eds.) prepared for Ministry of Housing, Physical Planning and Environment, The Netherlands, February 1988. (Table provided by Paul Chenard, Energy, Mines and Resources.)

# 5.0 SELECTION OF COST-EFFECTIVE MEASURES

## 5.1 Carbon Dioxide Emissions Reduction Target

To construct a greenhouse gas abatement scenario, the target recommended by the Toronto Climate Conference was used. Using the IFSD model, energy demand forecast implies a carbon dioxide reduction target of 291 million tonnes per year. This would reduce the estimated 2005 emissions of 627 million tonnes to 336 million tonnes, which is 80 percent of the 1988 estimated emissions of 419 million tonnes.

However, as noted in Section 4.5 above, the IFSD energy demand forecast probably includes some implicit energy efficiency improvements. This would cause the carbon dioxide reductions attributed to specific measures to be overstated. To adjust for this possible overstatement, the target is adjusted to 291 to 342 million tonnes per annum.

## 5.2 Selection Criteria

The selection criteria for carbon dioxide abatement measures is cost-effectiveness. The most cost-effective measures are selected first. This yields the largest possible reduction in carbon dioxide emissions for the lowest total cost.

The process of selecting carbon dioxide abatement measures is more complex than it sounds. There are two reasons for this:

- the reductions are achieved by direct and indirect means; and
- the emissions reductions for various measures are not always additive.

The adjustments needed to cope with these complications are discussed below.

## 5.3 Categories of Carbon Dioxide Emissions Reductions

Carbon dioxide emissions reductions can be achieved directly or indirectly through the following three categories of measures:

- direct reduction of carbon dioxide emissions through conservation, substitution and other measures that affect fossil fuel use in the residential, commercial, industrial and transportation sectors.

- indirect reduction of carbon dioxide through measures that reduce the use of electricity in the residential, commercial, industrial and transportation sectors. Reduced demand for electricity lowers the use of fossil fuel used to generate electricity and so lowers carbon dioxide emissions.

- substitution of non-fossil generation for fossil fueled generation. This lowers carbon dioxide emissions by reducing the amount of fossil fuel used to generate electricity.

The analysis proceeds by examining the carbon dioxide emissions reductions that can be achieved by each of these categories of measures in turn.

Most of the measures in the first category reduce the emissions of carbon dioxide and other greenhouse gases through reduced use of fossil fuel or substitution of a less carbonaceous fuel.

Measures that reduce the use of electricity affect emissions by the electricity generation sector. So called demand-side management measures, reduce the demand for electricity in a

specific sector. However, to determine the net impact or electricity generation, it is also necessary to consider measures that increase demand for electricity (e.g., electrotechnologies in the industrial sector) or increase the production of by-product electricity (e.g., cogeneration).

The net impact on the demand for electricity is added to the forecast growth in demand for electricity to get an adjusted demand to be supplied by the utility sector. The reduced demand for electricity supplied by the utility sector is converted into a reduction in the fossil fuel demand, and hence carbon dioxide emissions, forecast by the IFSD model.

The third category of measures consists of the substitution of non-fossil fueled generation for new and existing fossil fueled generation. The technical potential for this measure is defined as the amount of non-fossil generation capacity forecast by the IFSD model to be available by 2005.

### 5.4 Additivity of Emissions Reductions

Emission reductions for various measures are not always additive. For example, maintaining proper tuning of an automobile engine is estimated to reduce fuel use by ten percent. If the average fuel efficiency of automotive engines improves, the fuel savings and emissions reductions that can be achieved through proper tuning decline proportionally. There are a number of instances where the emissions reduction achieved by combinations of measures must be adjusted to reflect such interactions.

# 6.0 IMPACT ON TROPOSPHERIC OZONE

Measures that reduce carbon dioxide emissions also reduce emissions of other gases. Among the other emissions reduced are nitrogen oxides ($NO_x$) and volatile organic compounds (VOCs) which react in the presence of light to form ozone in the troposphere. The relationship between $NO_x$ and VOC emissions and ozone formation is reviewed in Appendix D. That relationship is used to estimate the effect of selected measures on tropospheric ozone formation.